A STUDY OF THE ORIGIN AND FATE OF AIR POLLUTANTS IN CALIFORNIA'S SACRAMENTO VALLEY

VOLUME II

by

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SUMMARY

An observational program was carried out in August 1980 to investigate the origin and transport of pollutants in the Sacramento Valley. The program was conducted jointly by the California Institute of Technology, Division of Chemistry and Chemical Engineering and Meteorology Research, Inc. The present volume includes the results of the program. A companion Data Volume contains the details of the data base generated during the study.

A total of six tracer releases were carried out during the program. Sampling was accomplished in terms of hourly-averaged tracer concentrations and numerous syringe samples were taken during automobile traverses and aircraft flights.

Five ozone monitoring stations were established in the area for the month of August to supplement the regular monitoring network. Air quality and meteorological parameters were recorded in the aircraft during a total of 36 flight hours.

Supplementary meteorological observations included pibal wind measurements at three to four locations during and after each of the tracer test periods. Surface wind measurements were made at four of the air quality sites and at the release site. An acoustic radar was operated near Georgetown from 11-27 August 1980 to observe inversion structure and vertical mixing depths.

Tracer releases wre made from Vallejo (2), from Sacramento (3) and from Woodland. The objectives of the releases, respectively, were to investigate the transport of the San Francisco Bay area plume into the Sacramento Valley (morning and afternoon cases), to document the transport of the Sacramento urban plume (two morning and one afternoon release) and to use the tracer sampling to determine the nature of the "Schultz Eddy" (Woodland release).

The first two tracer tests were conducted under conditions where the 850 mb temperatures were warmer than normal. Thereafter, an upper level trough influenced the area for the remainder of the field program so that conditions conducive to the occurrence of high oxidant values were not present.

Tracer material released into the San Francisco Bay area plume was observed to pass primarily into the San Joaquin Valley on one occasion and into the Sacramento Valley in the other test. An early morning release resulted in significant tracer concentrations in Lodi after which the material moved east and southeast into the Sierra slopes or the San Joaquin Valley. No significant impact was noted at Sacramento. A late afternoon release from Vallejo produced extensive downwind concentrations in the Sacramento Valley, aided by unusually strong south to north pressure gradients in the Valley. Extensive carry over of tracer material in the Valley was noted on the following morning.

Three releases from Sacramento showed the variety of transport routes which occur for the Sacramento urban plume. An afternoon release moved directly east and northeast from Sacramento into the Sierra foothills. Two early morning releases from Sacramento impacted the Valley as far north as Oroville and Red Bluff.

A final release from Woodland documented the transport characteristics of the Schultz Eddy. The eddy frequently exists in early to late forenoon. It provides a mechanism for recirculation of pollutants in the lower part of the Sacramento Valley below Chico. It also tends to restrict the marine air from the Bay area from passing northward into the Sacramento Valley during its period of existence. The eddy degenerates into a general southwesterly flow by midday.

Carry over aloft of tracer material from one of the Sacramento releases was observed by aircraft sampling over the middle of the Valley on the following day. This material fumigated to the ground around midday of the day after release in Chico and Marysville. These data indicated the potential for carry over of pollutants from one day to the next although the Valley was generally well ventilated during the period of the field program.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Introduction

The Clean Air Act of 1977 requires that counties not in attainment of Federal ambient air quality standards develop strategies that will reduce emissions sufficiently to achieve acceptable air quality levels. During the summer period, when insolation is greatest, ambient concentrations of oxidants frequently exceed those standards in portions of the Sacramento Valley. In response, the Air Resources Board, State of California (CARB), has undertaken a program to define the origin and fate of oxidant and its precursors in the Valley. It is only after such definition has been made that realistic control strategies can be developed.

To this end, Meteorology Research, Inc. (MRI) and the California Institute of Technology (CalTech) under sponsorship of the CARB conducted a study to acquire the data and understanding necessary for the development of this strategy. Specific objectives of the study were to:

1. Identify the major source regions for ozone and precursors which may affect the Sacramento Valley.
2. Investigate the transport of ozone and precursors into, within, and out of the Valley.
3. Acquire an aerometric data base that can be used in air quality simulation of the photochemical formation and transport in the Valley.

To meet these objectives, an intensive field program was carried out in August 1980 in order to obtain supplemental meteorological and air quality data in the Sacramento Valley during periods of high oxidant levels; and to release airborne tracer and monitor its movement into, within, and out of the Valley. The key elements of the field program were the following:

- Six atmospheric tracer tests which consisted of two releases from the North Bay area, three releases from the Sacramento area, and one release from Woodland. The Bay area tracer releases were designed to document transport from that area into the Sacramento Valley and subsequent transport within. The Sacramento experiments were designed to document the impact of urban emissions from different locations within the greater metropolitan area at varying times of the day. The last release was designed to study the transport during the Schultz Eddy. A summary of the tracer tests is given in Table 1.0.1.

- Air quality and meteorological sampling from an airborne platform during episodes of high oxidant and in support of the tracer experiments.
- Winds aloft and temperature sounding observations on a scheduled basis in support of the tracer experiments and aircraft sampling.
- The acquisition of supplemental surface winds, ozone, and nephelometer (scattering extinction coefficient of atmospheric aerosol particles) data on a continuous basis.
- The operation of an acoustic radar for the duration of the field study.

Specific locations and schedules of observations have been reported in two data volumes; one prepared by CalTech containing the tracer data and another prepared by MRI containing the air quality and meteorological data. The reduced data were presented therein in tabular and graphical form. The data have also been transcribed to a computer compatible format and submitted to the CARB.

This report discusses the findings of the field program and attempts to integrate these findings with previous studies whenever possible. In Section 4, the experimental periods are discussed individually and all pertinent tracer, meteorology, and air quality data are included.

Table 1.0.1 Summary of Tracer Experiments

	Date	Time (PDT)	Location	Rate	Purpose
Test 1	8/09/80	0620-1120	6 km NE Vallejo	41 kg SF_6/hr	Transport from Bay Area
Test 2	8/13/80	0600-1100	Sacramento(15th & R St.)	47 kg SF_6/hr	Sacramento urban plume transport
Test 3	8/20/80	1500-1900	Sacramento(Auburn & Watt Ave.)	40 kg SF_6/hr	NE Sacramento urban plume transport
Test 4	8/23/80	1500-1900	6 km NE Vallejo	43 kg SF_6/hr	Transport from Bay Area
Test 5	8/25/80	0700-1100	Sacramento(15th and R St.)	49 kg SF_6/hr	Sacramento urban plume transport
Test 6	8/28/80	0600-1000	Woodland Airport	26 kg SF_6/hr	Schultz Eddy transport

2. Meteorological Environment

In the absence of synoptic scale disturbances, the surrounding terrain dominates the meteorology of the Sacramento Valley. Differential heating and pressure gradient differences between the ocean and interior regions provide the major forces which control the air circulation in the Valley. Typically during the warm months of the year, when oxidant levels are highest, a semi-permanent high pressure area is located off the California coast in conjunction with a thermal trough positioned inland over the interior of California. Under those conditions, cool marine air is channelled into the Sacramento Valley through the Carquinez Straits. The intrusion of marine air is associated with a southerly flow throughout the Valley during afternoons. In instances when the impulse is particularly vigorous, the generally southerly flow prevails throughout the night as well. But most often during the late night and early morning, drainage flows prevail in the northern and western portion of the Valley where the marine intrusion is weakest. Although greatly reduced, a southerly flow continues early in the morning in the southeastern side of the Valley and the opposing flows form a counterclockwise eddy which generally affects the southern half of the Valley (Fitzwater, 1981). As the atmosphere stabilizes in the early evening, a low-level southerly jet often develops with high velocities capable of transporting pollutants over large distances.

These mesoscale meteorological features, along with slope flows and Sacramento area winds, are subjects of discussion in the following sections.

2.1 Terrain

The Sacramento Valley extends northward from the Delta area to the Cascade Range in northeastern California and includes the northern one-third of the Central Valley (Figure 2.1.1). The Valley floor rises gradually from 17 ft msl at Sacramento to 580 ft at Redding, about 150 miles to the north. The average width of the Valley is about 50 miles. The most prominent topographic feature within the Valley is Sutter Buttes which rises to over 2100 ft msl and covers approximately 80 square miles.

The Valley is bordered on the west by the Coast Range with peak elevations of around 7000 ft north of Clear Lake with somewhat lower elevations to the south. To the east, the Valley is bounded by the Sierra Nevadas with peak elevations of 8000-9000 ft in the areas of interest. The principal low-level passes (around 4000 ft) through the Sierras lie along the Feather and Pit Rivers, northeast of Oroville and Redding, respectively. In the central Sierras, passes through the mountains (Highways 50 and 80) are near 7000 ft msl.

The primary gap in the Coastal Range occurs in the area of the Carquinez Straits where the Sacramento River empties into San Pablo Bay. This gap permits the important intrusion of marine air into the Sacramento Valley.

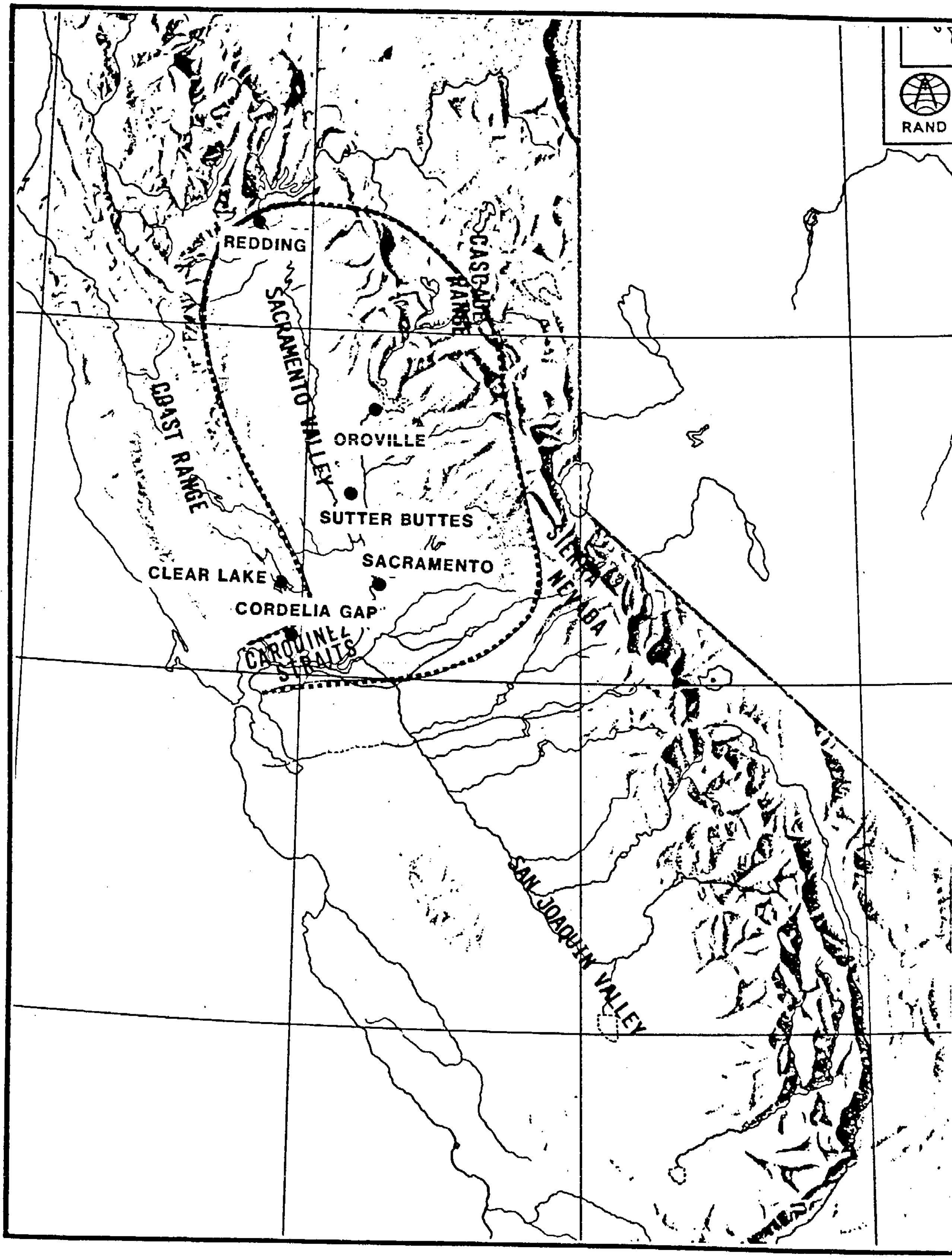

Figure 2.1.1 The Central Valley of California
Dashed line encompasses area of study.

2.2 Mesoscale Features of the Flow

Marine Air Intrusion

The persistence of the Pacific High off the California coast during the summer months in conjunction with the developmentof low pressures over the California interior creates pressure gradients which power a surge of marine air onshore. Due to a combination of the barrier presented by the coastal ranges and the vertical stability imposed by the coastal subsidence inversion, air is channelled principally through the Carquinez Straits and Cordelia Gap into the Central Valley of California. The flow once through the straits diverges into the San Joaquin and Sacramento Valleys. A representative streamline pattern for the most prevalent summertime flow type from an earlier study by Smith et al. (1977) is shown in Figure 2.2.1. Schultz (1975) has shown that summer marine air intrusion to the Central Valley is typically a 24-hour phenomenon, with the weakest development during the morning and lulls occurring at times until noon. The morning lull is followed by a strong surge in the afternoon which lasts all night. Schultz further noted that 8 years of smoke observation statistics show restricted visibility due to smoke occurrences only during the lulls before noon. The persistence of the flow through the straits can be seen on Figure 2.2.2, a time-height cross section of the winds aloft over Rio Vista during a 24-hour period (23-24 August 1980) in the current study. Low level west-southwest winds were in excess of 7 m/s from the start of observations (1400 PDT) until 0800 PDT on the following morning. At that time a relative lull is observed to have developed. Speeds in excess of 11 m/s were observed from midnight until daybreak. Maximum speeds reached 14 m/s within the high velocity layer which was confined to the lower 500 m. These measurements are consistent with the findings of Schultz from long-term multi-level wind measurements on a 1500 ft TV tower at Walnut Grove some 12 miles northeast of Rio Vista.

The diverging nature of the flow through the Carquinez Straits is clearly illustrated from the wind direction frequencies from Stockton and Sacramento as shown below in Table 2.2.1. For all hours in the June through September period, the flow is from the southerly quadrants 89 percent of the time at Sacramento and primarily from the northerly quadrants (85%) at Stockton.

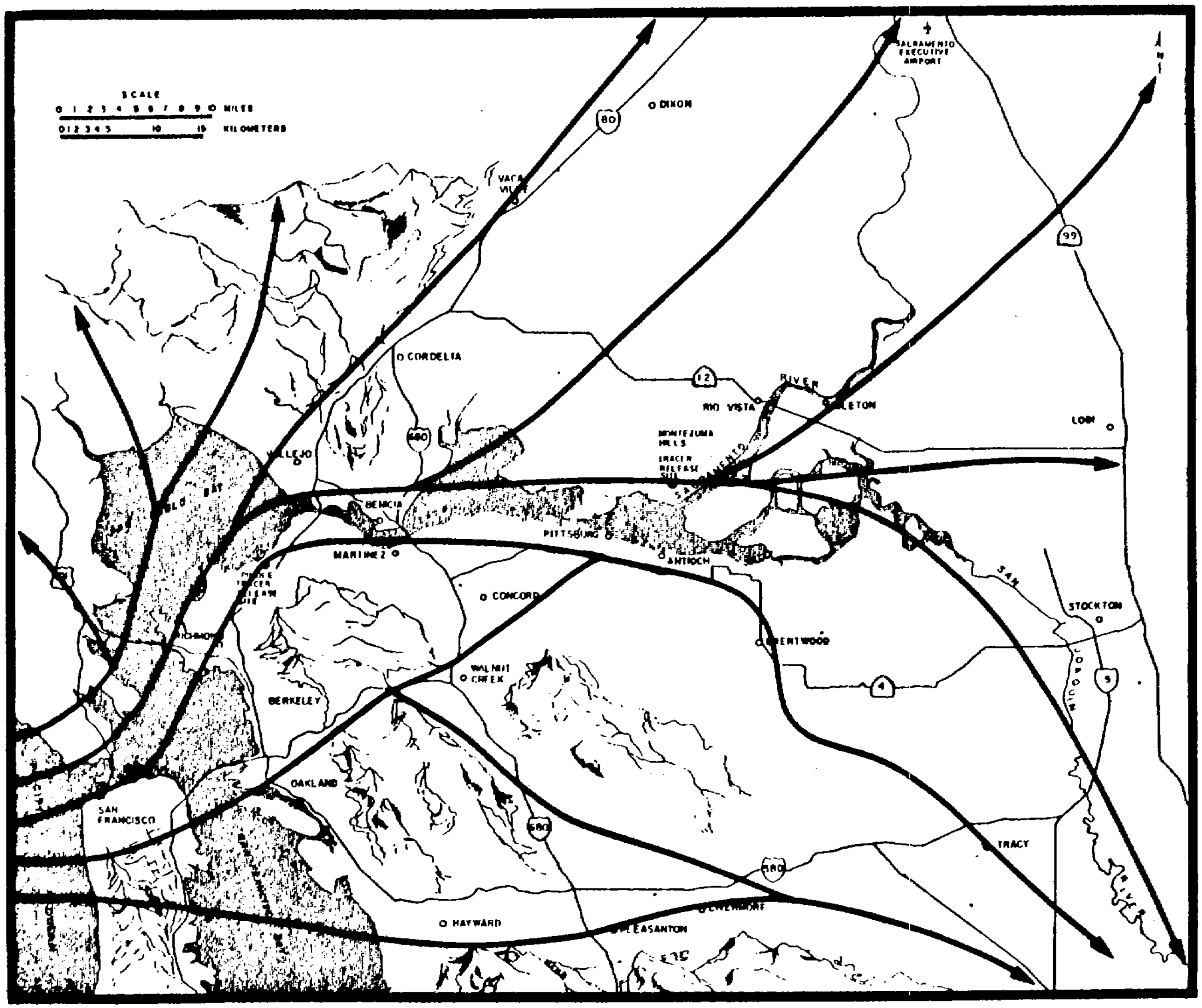

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Figure 2.2.1. Representative Streamline Pattern through Carquinez Straits for Most Prevalent Summertime Flow. (From Smith et al.)

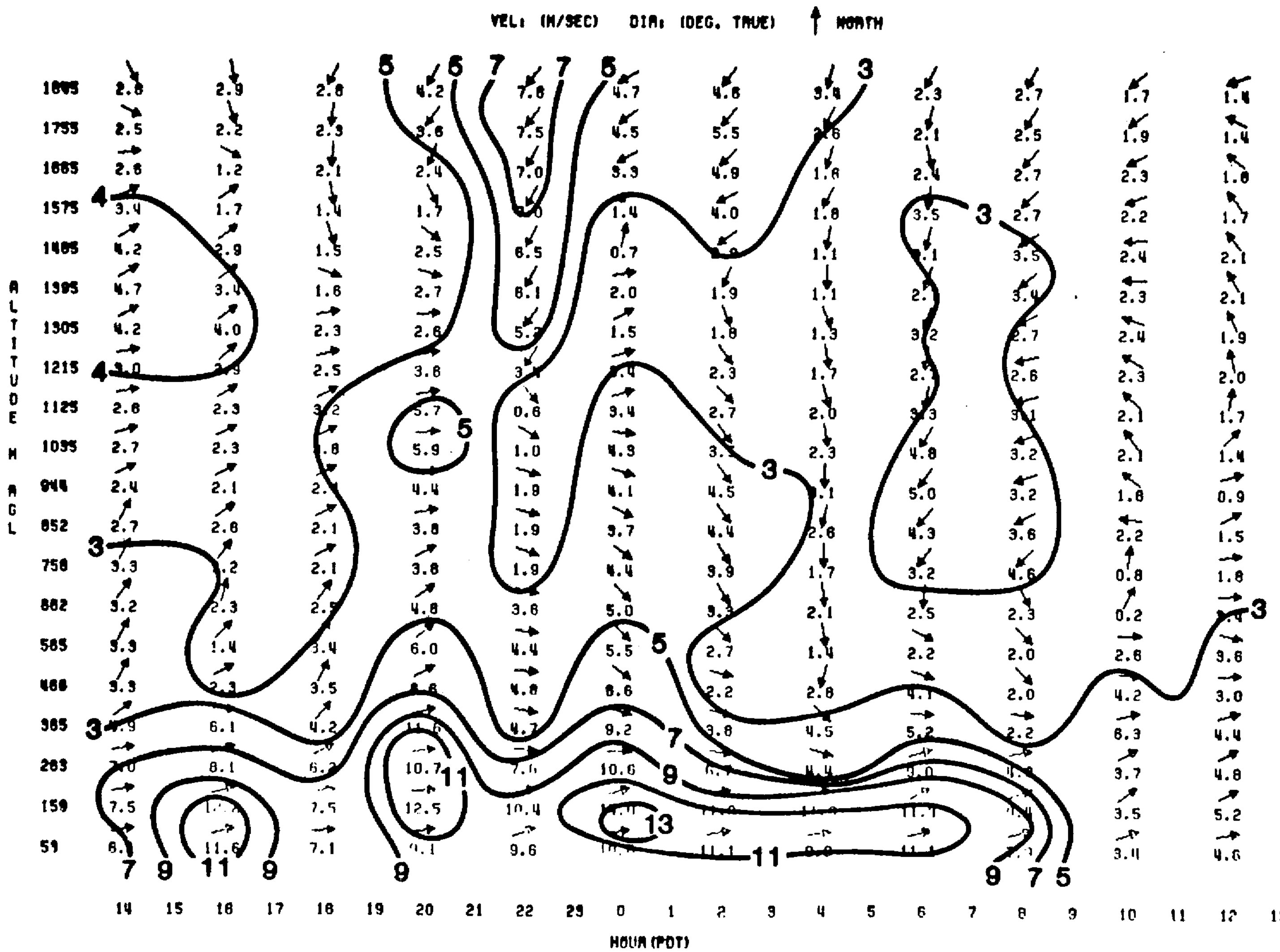


Figure 2.2.2 Vertical Time Section of Winds Aloft at Rio Vista on 23-24 August 1980. Wind Speed in m/s.

Table 2.2.1 Frequency of Wind From Each Quadrant
Percent for all hours 1971-72.

		NE	SE	SW	NW
Sacramento	June-July	2	30	62	6
	Aug-Sept	4	32	53	11
Stockton	June-July	21	3	11	64
	Aug-Sept	19	3	11	66

The northward extent of marine air intrusion into the Sacramento Valley has been documented by Schultz and Fitzwater with data from numerous ground monitoring sites. They found that it typically encompasses the entire Valley in the late afternoon and early evening. In the early morning, their surface wind statistics show a weak northerly or drainage flow developing at Redding, extending south by daybreak along the west side of the Valley. On the east side of the Valley, a southerly flow still persisted although exhibiting its weakest stage. This description is reflected in the wind frequency data for Redding and Chico shown in Table 2.2.2. Chico statistics display a continuation of the persistent southerly flow previously shown at Sacramento. Redding wind statistics, on the other hand, show a distinct diurnal character. Southerly winds predominate during summer afternoons; northerly winds frequently occur during the late night and early morning hours.

Table 2.2.2. Frequency of Wind From Each Quadrant
Percent for all Hours 1971-72.

	REDDING				CHICO			
Month	NE	SE	SW	NW	NE	SE	SW	NW
Jun	11	26	12	51	4	70	18	8
Jul	10	33	7	50	2	65	28	5
Aug	9	36	10	46	3	68	23	6
Sept	21	18	10	51	6	54	16	24

Schultz Eddy

The opposing flows generally converge between Red Bluff and Chico (Unger 1979). Near daybreak, a counterclockwise eddy develops in the southern half of the Valley which persists until around noon, at which time a fresh marine air impulse again invades the area. The eddy development is of importance from an air quality standpoint as it provides a method by which Sacramento urban air can be transported cross-valley to the west side. Unger identified three wind patterns occurring in the Sacramento Valley during August 1979 from daily 18Z (11 PDT) surface streamlines. The patterns which he identified and frequency are as follows:

- Southerly wind throughout Valley. 23%

- Convergence pattern, with south winds in the southern Valley and north winds in the northern Valley. 47%

- Indeterminate or complex wind pattern. 30%

Many instances of the third or indeterminate wind pattern may be due to a combination of the effects of surface stability on air flow and the moderate threshold speed of most anemometers. The data collected by Fitzwater and Schultz atop Sutter Buttes (elevation 2100 ft-msl) show a 72% frequency of occurrence of northerly winds between 10-11 PDT; a number comparable to the combined frequencies of the last two of Unger's patterns. The Fitzwater and Schultz Sutter Buttes data is in good agreement with the limited data base taken from the same Sutter Buttes site during the current study. Those data, shown in wind rose form on Figure 2.2.3, show a 64% occurrence of northerly flow in the 07-12 PDT period (disregarding calm occurrences). During the remaining periods, there is a strong preference for flow from the southerly quadrants. The 28 August 1980 case study, when intensive measurements were made under eddy conditions, was consistent with the earlier studies; showing development early in the morning and disintegration by 11 PDT. The eddy showed maximum development from 07-09 PDT at Woodland and Dunnigan. Northerly flow was observed at those locations through a layer from the surface to 600 m.

The evolution of the eddy during a selected 24 hour period can be viewed from a series of surface streamlines developed by Fitzwater and

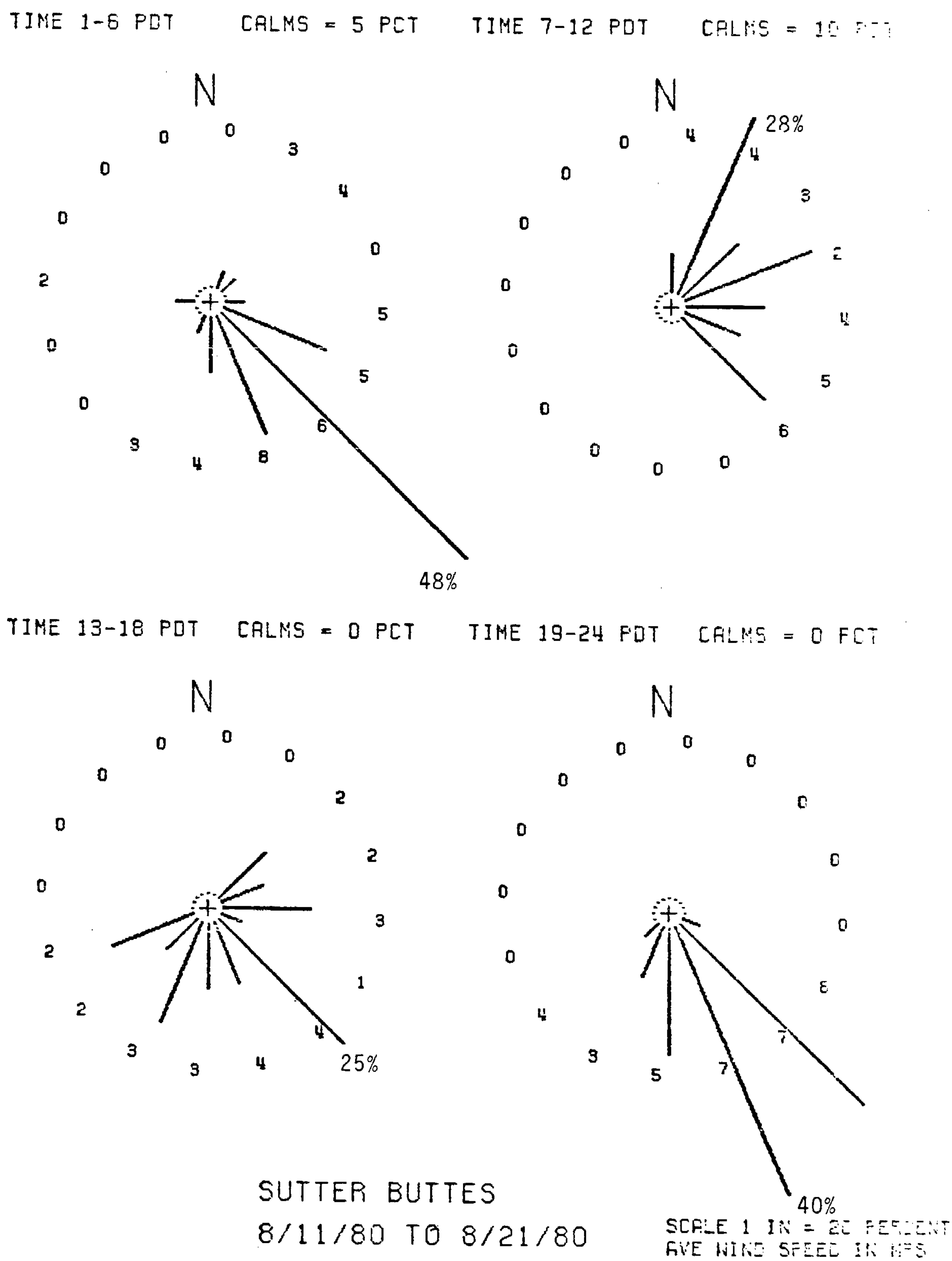


Figure 2.2.3 Wind Roses for Sutter Buttes

reproduced here on Figure 2.2.4. During this case study, the marine flow dominated the lower half of the Sacramento Valley from the early afternoon until about midnight. By 03 PDT (Figure 2.2.4.E), a northerly flow is seen developing on the west side of the Valley south of Sutter Buttes followed by a well-developed eddy encompassing the whole southern half of the Valley by 06 PDT. The period 10-11 PDT was a period of transition as the eddy collapsed prior to a new surge of marine air into that region. The possible recirculation of pollutants in the southern half of the Valley due to this mechanism is clearly evident. For several hours, emissions from the Sacramento area can be transported cross-valley and could conceivably even recirculate back through Sacramento.

Nocturnal Jet

As suggested above, surface wind data offer only a partial explanation of the transport winds within the Valley. While surface winds show a general decrease in velocity during the night, on numerous occasions a low level southeast jet develops. The jet, which forms as the atmosphere stabilizes and the surface layer decouples from the air aloft in the presence of a sufficient driving force can, according to Fitzwater and Schultz, attain speeds in excess of 35 mph between 500 and 1000 ft above the surface. They further characterized the night jet as extending horizontally across the Valley with stronger development on the east side; and typically dissipating by sunrise. They found the jet to be strongly developed to at least up valley 60 mi north of Sacramento. An example of the night jet development on one instance during the current study is depicted in Figure 2.2.5. The figure shows a time-cross section of the Sacramento pibal winds on 20-21 August 1980. This instance is particularly interesting in that otherwise the wind field was generally light thus underscoring the jet occurrence. Consistent with the earlier study, the jet clearly developed shortly after sunset and, after reaching a peak between 01 and 04 PDT, dissipated around sunrise. The effects of the jet are seen mainly between 100 and 600 m above the ground. This layer is well within the afternoon mixing layer. Thus the jet provides a means of transporting pollutants over large distances in a short time. Furthermore, the tranport is directed north towards regions which contain no large sources of ozone precursors.

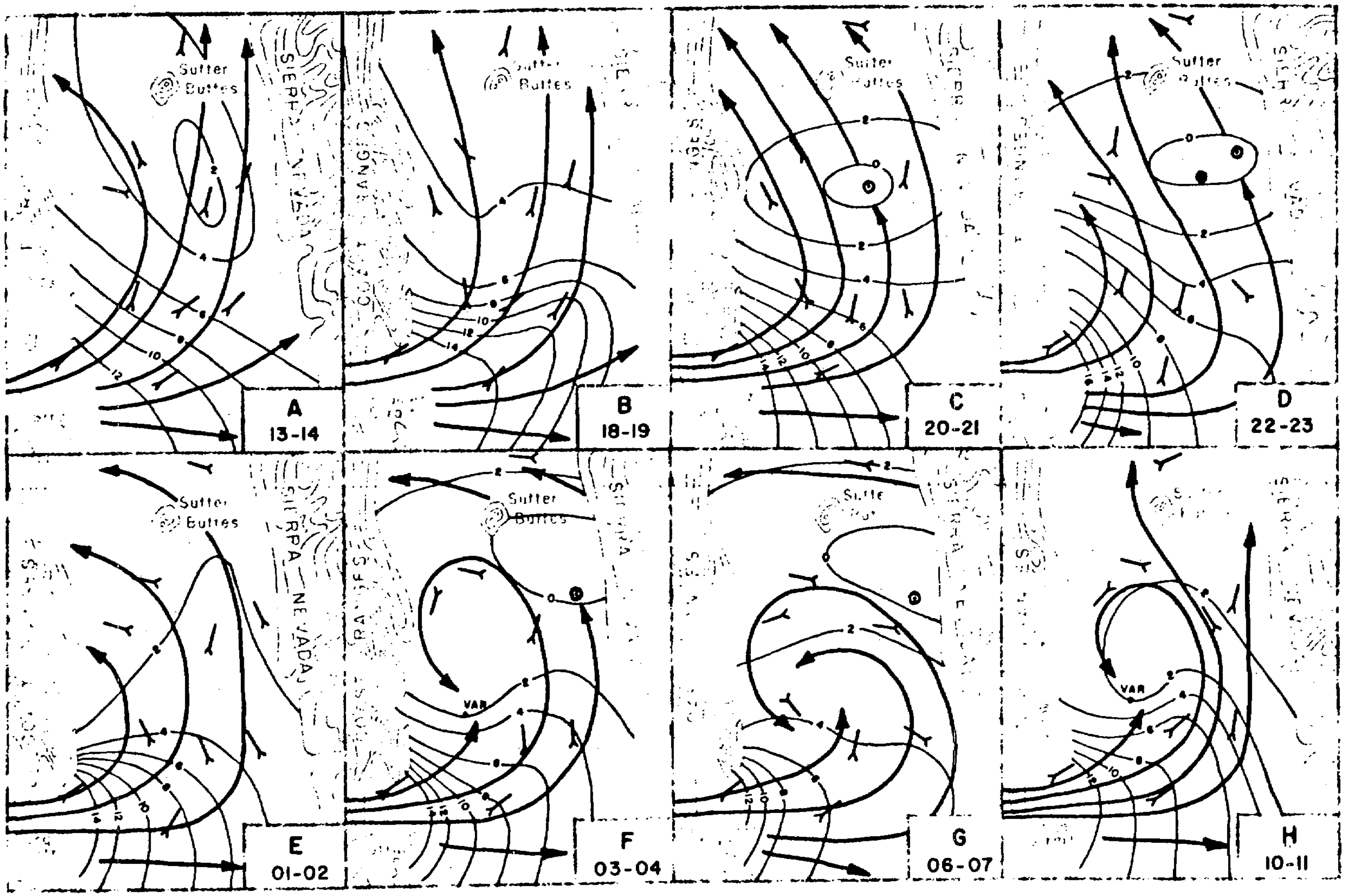


Figure 2.2.4 Streamline diagrams of surface winds on July 28-29, 1966. Isotachs are in m.p.h. and small direction arrows are at station locations. Based on average conditions during hour specified. After Fitzwater (1966).

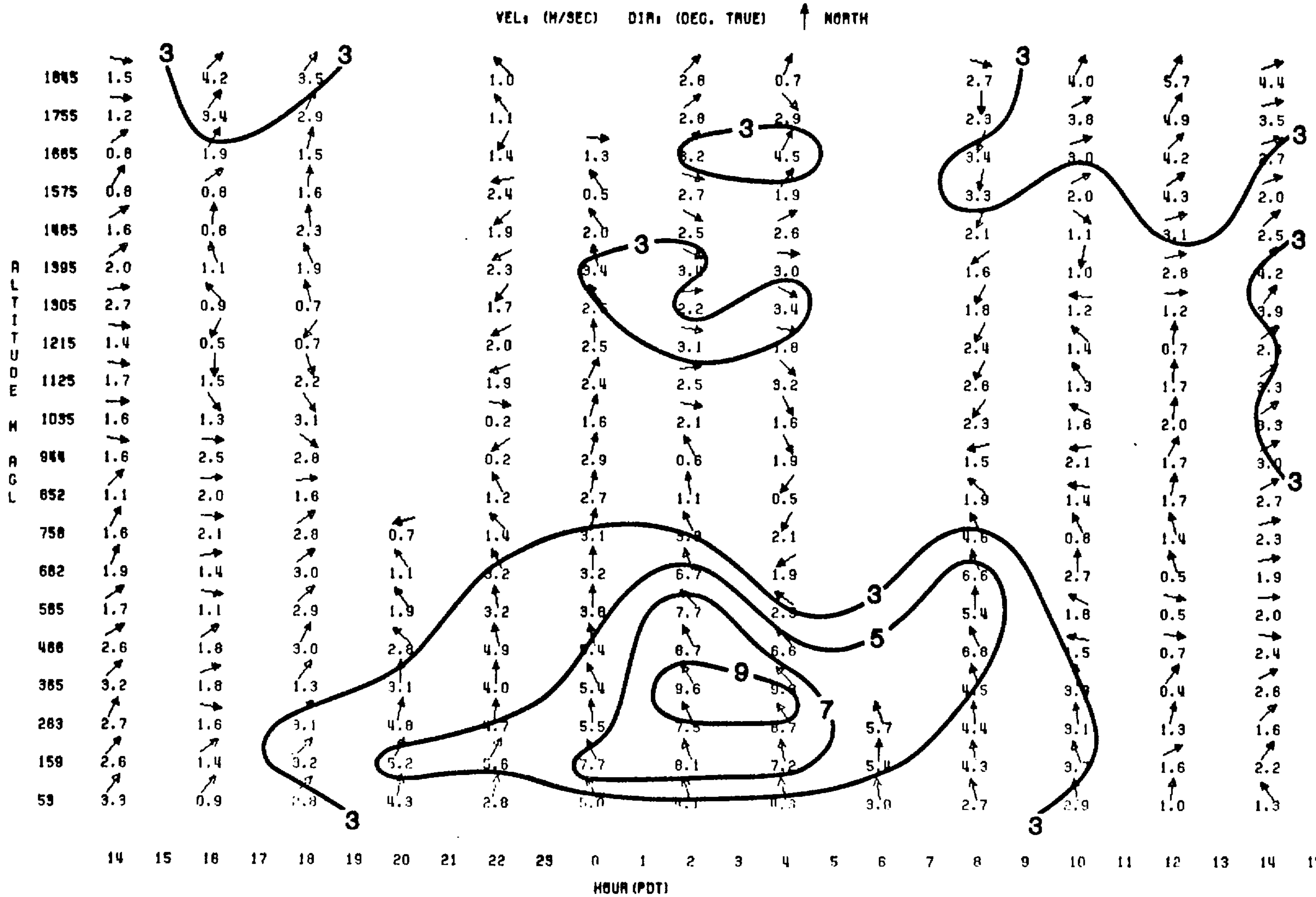


Figure 2.2.5 Vertical Time Section of Winds Aloft at NE Sacramento on 20-21 August 1980. Wind Speed in m/s.

During the current study, a nocturnal jet was observed during 5 of the 6 test periods. For purposes of classification, an increase in wind speed with height observed within the sub-inversion layer and persisting during the night was defined to constitute a nocturnal jet occurrence. Only during the 9-10 August test were these conditions not met. Table 2.2.3 summarizes the nighttime winds aloft observations, pressure gradients and inversion characteristics. The strongest jet was observed on the evening of 13-14 August when pressure gradients were well above the average. Otherwise, the relationship between the pressure gradients and jet magnitude is not clear. There does not appear to be any relationship between the nocturnal inversion and jet occurrence or magnitude in this limited sample.

Slope Flows

Due to differential heating, flow characteristics in that portion of the airshed adjacent to the mountains are typically directed upslope during afternoons. The west-facing slopes of the Sierras and Cascades are particularly well situated for this development as they have maximum exposure to the afternoon sun. After sunset, as gravity forces become dominant, the flow reverses and is directed down the slopes. As such, slope flows have an impact on the transport of Valley pollutants and can provide a mechanism for ventilation.

During the current study, recording anemometers were sited at four locations in the Sierra foothills. Table 2.2.4 gives a summary of the most frequent wind directions during the afternoon and nighttime periods. The complete set of data are included in the data volume to this report. The diurnal nature of the flow is clearly shown at all locations, although the local terrain plays a strong role in determining specific directions. The 7-12 and 19-24 PDT periods reflect the transition between the upslope and downslope flows and are typically bimodal. The wind roses for White Cloud shown on Figure 2.2.6 serve as an example of the slope flow characteristics.

The times of onset and cessation of upslope flow were similar at all sites and not influenced by exposure. A weak upslope flow usually developed by 10-11 PDT and typically ceased between 18-19 PDT. Strength of the flow, however, like the direction was site dependent. The White Cloud site was at the 4340 ft elevation atop the divide between the south fork of the Yuba River

Table 2.2.3. Nocturnal Jet Occurrences During Case Studies

Date	Jet Occurrence	Max Wind Speed** @ 06 PDT	SAC-RBL ΔP* 22 PDT	SAC-RBL ΔP* 04 PDT	SFO-SAC ΔP* 22 PDT	SFO-SAC ΔP* 04 PDT	Inversion Top (m)	Inversion Magnitude(°C)
8/09-10	no	3 m/s	0.3	0.0	2.8	2.8	700	16.5
8/12-13	yes	9 m/s	2.7	0.4	-	3.9	700	14.9
8/13-14	yes	15 m/s	1.9	0.5	3.9	2.3	700	5.9
8/20-21	yes	6 m/s (263)	1.3	0.8	3.2	2.1	650	11.8
8/23-24	yes	5 m/s	0.8	0.7	1.5	1.8	650	10.4
8/24-25	yes	9 m/s	-0.5	-0.1	3.2	2.0	450	10.4
8/25-26	yes	10 m/s (263)	0.6	0.3	2.5	1.8	650	11.9

*pressure in millibars
**Altitude of maximum - 365 m except 263 as noted

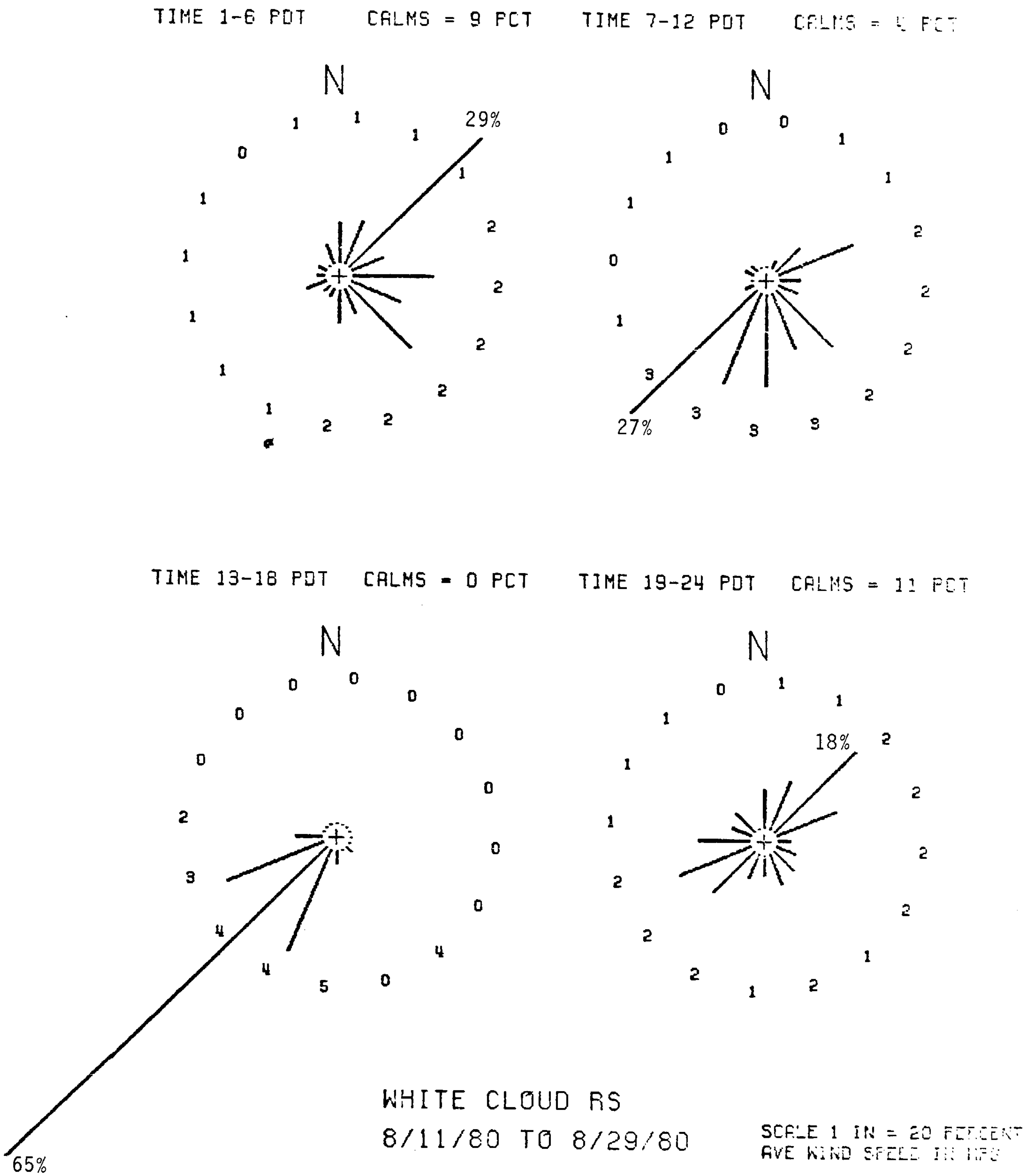


Figure 2.2.6 Wind Roses for White Cloud

and north fork of the American River. Winds at this location exhibited the strongest upslope velocities, mostly in the 3-5 m/s range. Drainage flows at White Cloud, as at the other sites, were always less than 3 m/s. The Foresthill site was located at 3225 ft atop of the divide between the north and middle forks of the American River, and the Georgetown site was at 3004 ft on the divide between the Rubicon and south fork of the American Rivers. Both sites were within the forest canopy and experienced extremely low wind speeds. All but 3 of 900 observations were less than 3 m/s. During the nighttime hours, Georgetown had a 70% occurrence of calm wind conditions. The monitor at Placerville, although having an excellent exposure, measured velocities mainly less than 3 m/s. However, the number of observations at that site were small due to mechanical difficulties. Wind roses for the Foresthill, Georgetown and Placerville sites are shown in Figures 2.2.7 to 2.2.9.

Table 2.2.4. Summary of Most Frequent Wind Direction in the Sierra Foothills

	Time (PDT)	
	01-06	13-18
White Cloud	NE	SW
Foresthill	ESE	S
Georgetown	Calm	SSW
Placerville	ENE	WSW

Note: The locations of these sites are shown on Figure 3.1.3.

The air quality measurements at these locations showed little evidence of significant transport from the valley floor. Smith et al. (1981) in a similar study of the San Joaquin Valley flow and ventilation characteristics concluded that slopes are not as effective a pollutant removal mechanism as previously thought. They were able to show that the flux from the Valley floor may be only 20-30% of the total flux at high elevations. Much of the slope air is drawn from elevations well above the Valley floor. The Sacramento and San Joaquin Valleys share many of the same characteristic terrain and flow features. Ozone reservoirs aloft over the Valley floor were observed in both studies which could impact the western Sierra slopes (see also Duckworth and Crowe, 1979).

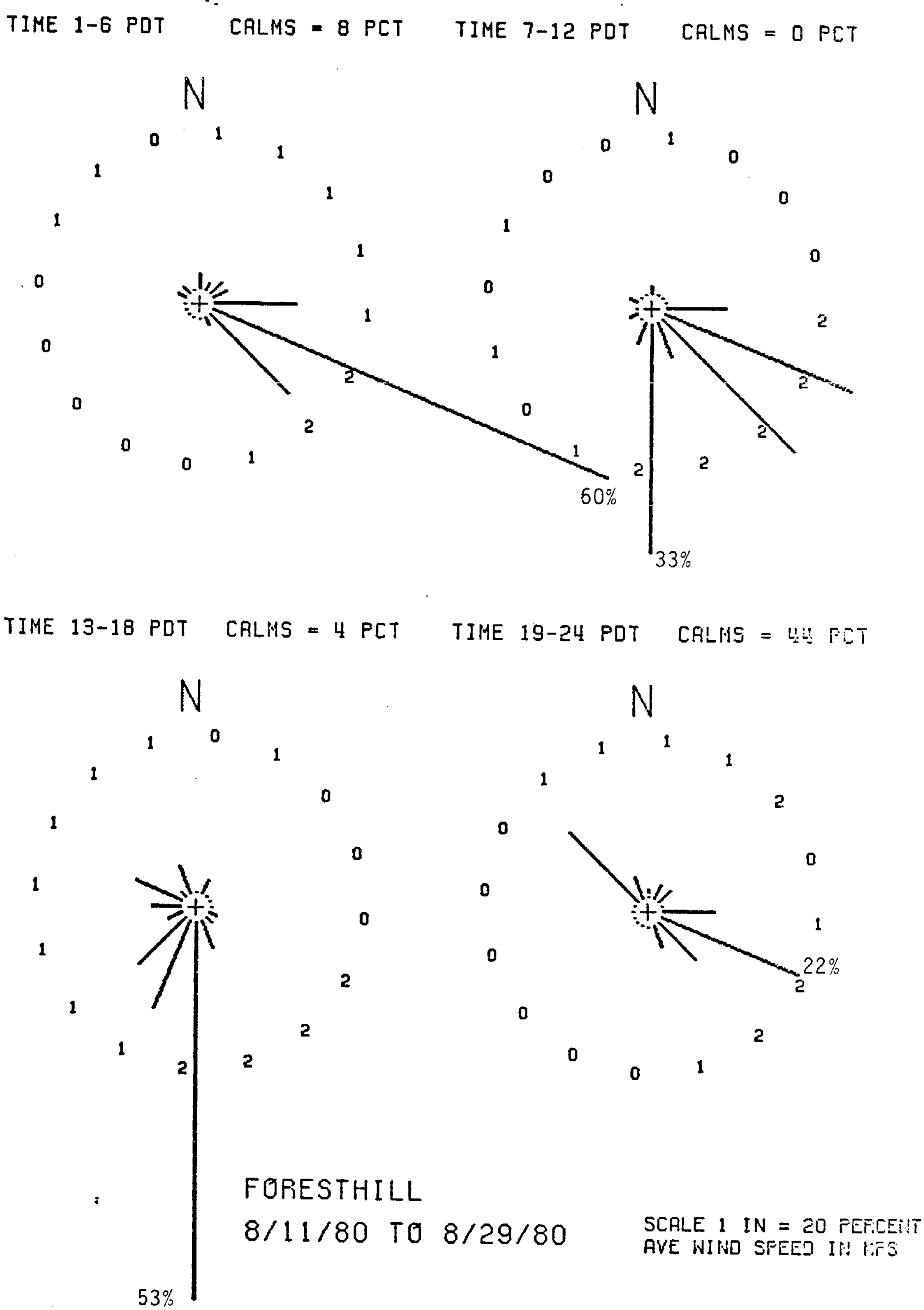


Figure 2.2.7 Wind Roses for Foresthill

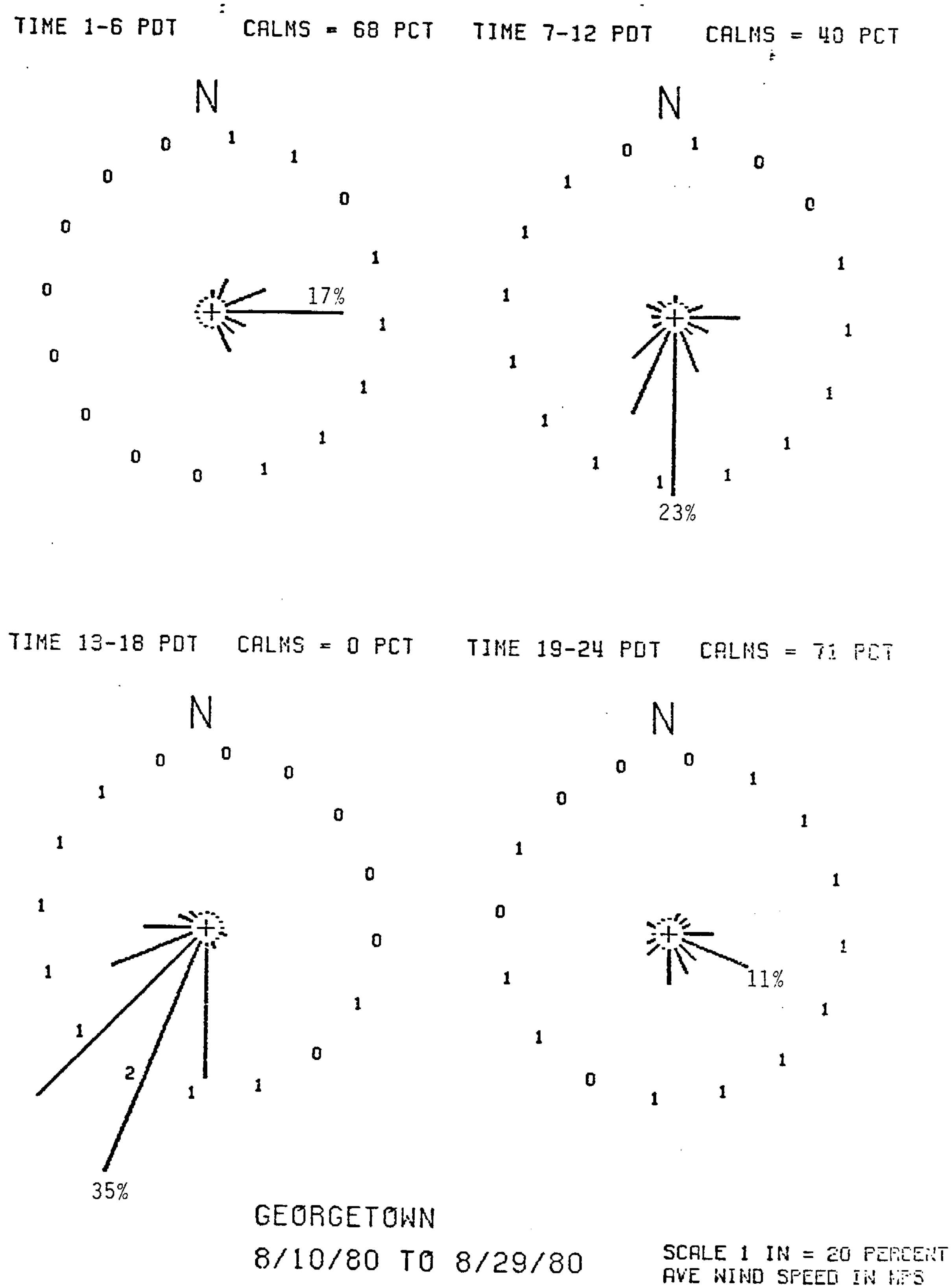


Figure 2.2.8 Wind Roses for Georgetown

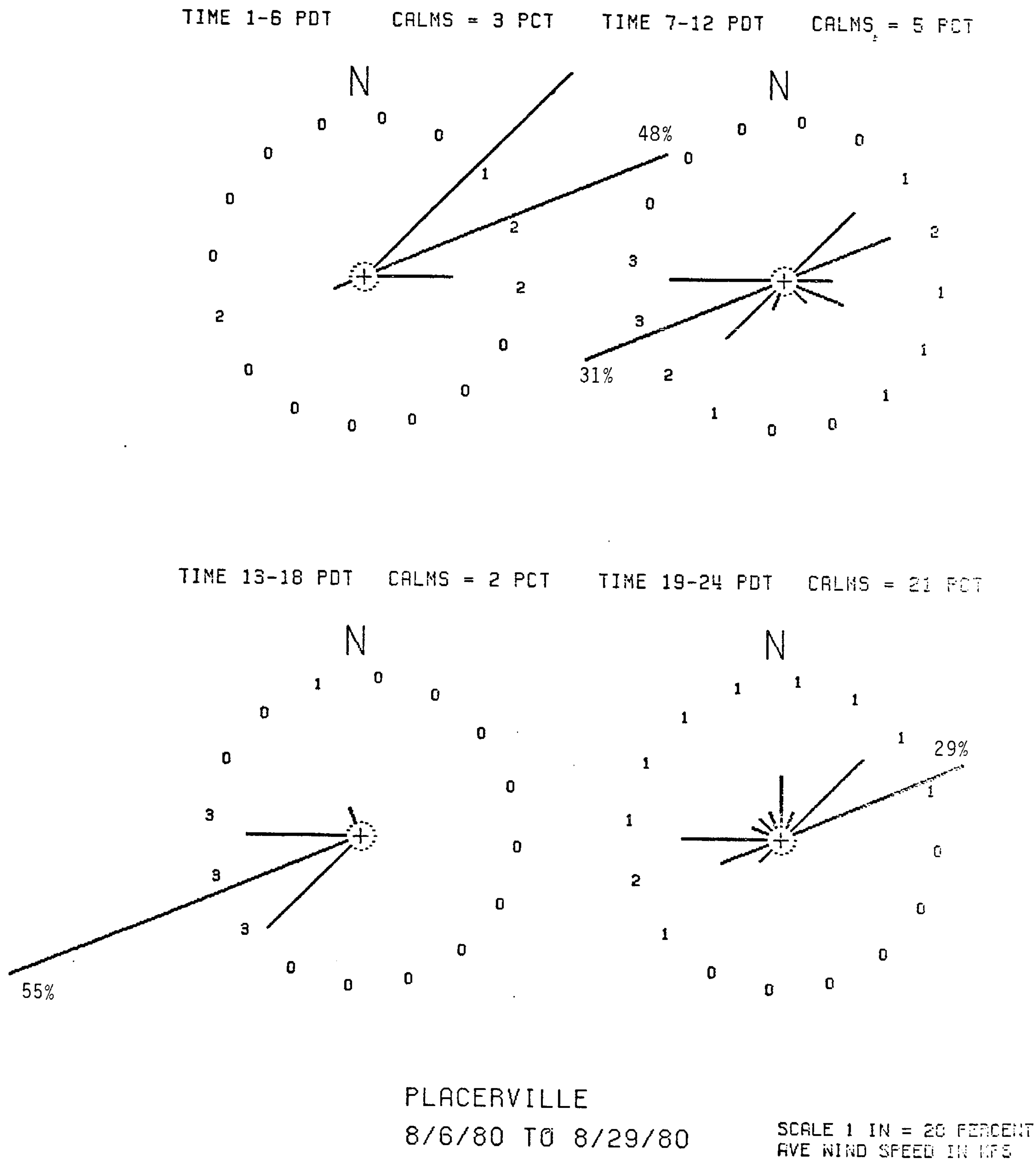


Figure 2.2.9 Wind Roses for Placerville

2.3 Sacramento Area Winds

Prevailing flow patterns in the Sacramento area are of special concern since this region has been identified as the greatest source of oxidant precursors in the Valley. Urban development has extended primarily north and east such that the greater Sacramento area extends nearly to Folsom Lake in the Sierra foothill region. The east-west extent of the greater Sacramento area is about 20 mi. Since the effects of slope induced flows decreases with distance from the slopes, emissions from varying locations within the Sacramento area are subject to different transport regimes.

Average wind vectors from four locations in the Sacramento area are plotted in their relative geographic locations on Figure 2.3.1. The data base consists of the 12 days in August when tests in the current study were underway. The winds on the figure have been grouped into eight 3-hour periods. The primary features of the data on Figure 2.3.1 are:

1. Metro airport and McClellan AFB, sites north of Interstate 80, show a greater occurrence of winds with an easterly component than do the locations to the south. McClellan AFB does, however, show periods of winds with a westerly component whereas Metro winds do not.

2. With the exception of Metro, southwest flow prevails during the afternoon in Sacramento. The winds from Mather AFB, the most eastern site, generally show a greater westerly component. This feature is the effect of its closer proximity to the mountains.

3. During the 00-08 PDT period, there was generally a south to southeast flow over the entire Sacramento area.

4. Peak velocities were observed at all locations at about 19 PDT (18-20 PDT).

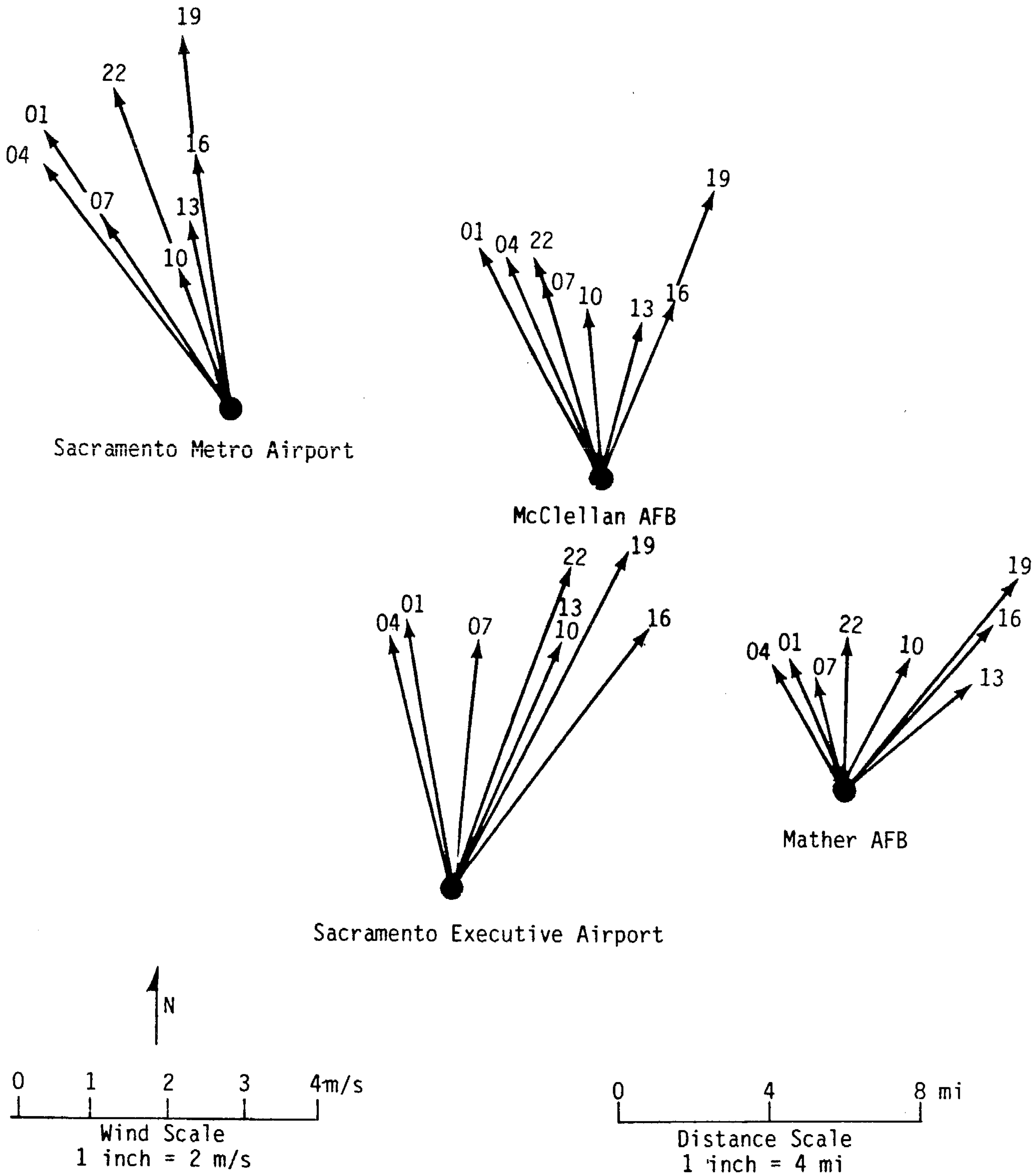


Figure 2.3.1 Average wind vector during tracer tests (12 days) Sacramento Area. Three hour grouping. Hours shown are mid-period in PDT. Geographic location of wind sites are relative to position on figure.

5. The winds generally show only a moderate decrease in velocities during the night. The lightest wind speeds were observed during the 09-14 PDT period. Mather AFB winds appear overall lighter than at the other locations.

The features described above suggest that the urban plume from the greater metropolitan area can potentially impact an area which covers a large region extending from northwest of the city to the east. The downwind impact from any particular source is dependent upon the location and time of emission. Pollutants trapped in the nocturnal inversion generally do not have the opportunity to accumulate in the Sacramento area.

To check as to the representativeness of the limited amount of data used in the preceding discussion, the average wind vectors calculated for Executive Airport were compared with calculations made by Duckworth and Crowe (1979) for the same location over a longer period during July 1978. The diurnal characteristics of the two data sets are in very good agreement. Resultant wind speeds during the southwesterly period average about 7 mph during the earlier study as compared to 8 mph during this study.

2.4 Overview of the Meteorology During the Test Period

The following section describes the general conditions during the August 1980 field study. The overall meteorological conditions are summarized on the basis of pressure gradients, temperature, both aloft and at the surface, and mixing depth. The data are compared with long-term means wherever possible.

Pressure Gradients

In the absence of strong synoptic scale features such as frontal systems moving through Northern California, flow patterns in the Sacramento Valley are dominated by local pressure gradients. The pressure gradients (reduced to sea level) between San Francisco and Sacramento (SFO-SAC) and between Sacramento and Red Bluff (SAC-RBL) have been used to indicate the diurnal and daily variations in the pressure gradient influence. Since typically changes in pressure gradients reflect regional variations in the pressure field, other locations may be used as well. However, for this report, the SFO-SAC and SAC-RBL differences are used to define the west-east and south-north gradients, respectively.

Table 2.4.1 shows the average diurnal variation in pressure gradient for the field study period and gradients experienced on test days are summarized in Table 2.4.2. Minimum pressure gradients in both the west-east and south-north directions occur in the midmorning and maximum gradients occur in the late afternoon and early evening. This cycle is also illustrated in Figure 2.4.1 for the SAC-RBL pressure gradient. Note that surface wind speeds at Sacramento, discussed in a previous section, correspondingly show a general lull in the midmorning and reach a maximum between 18-2000 PDT. Important differences between the south-north and west-east pressure gradients exist as well. The SFO-SAC pressure gradient was always positive during the study periods reflecting the continuous 24 hour onshore flow typically observed in the Carquinez Straits. The south-north gradient, on the other hand, had numerous instances of zero or negative values. Plotted on Figure 2.4.2 is the daily 1700 PDT SAC-RBL pressure gradient and the upvalley component of the 1700 PDT surface wind at Sacramento Executive Airport. Upvalley flow is directed from Sacramento toward Red Bluff. The strong relationship between the two parameters is readily apparent. Strong upvalley flow is nearly always associated with peaks in the pressure gradient and a weak gradient is associated with a small upvalley wind component.

Table 2.4.1 Diurnal Variations in North-South and West-East Pressure Gradients for the Period 9-28 August 1980

Time (PDT)	04	10	16	22
San Francisco-Sacramento P (mbs)	2.2	2.0	3.0	3.0
Sacramento-Red Bluff P (mbs)	0.9	0.0	2.0	1.5

Table 2.4.2 West-East and South-North Pressure Gradients (mbs) on Test Days - August 1980

	SFO-SAC Time(PDT)				SAC-RBL Time(PDT)			
	04	10	16	22	05	11	17	23
9	3.1	1.9	2.1	2.8	- 0.1	0.9	0.8	0.3
10	2.8	2.1	2.7	2.6	0.0	0.8	0.7	0.8
13	3.9	3.5	5.1	3.9	0.4	1.7	2.3	1.9
14	2.3	2.1	4.0	3.2	0.5	1.5	1.7	0.5
20	1.6	1.5	3.1	3.2	0.3	0.1	1.3	1.3
21	2.1	1.9	2.8	3.9	0.8	0.9	1.1	1.5
23	1.5	1.2	2.3	1.5	0.7	1.7	2.7	0.8
24	1.8	2.8	2.8	3.2	0.7	0.9	1.2	-0.5
25	2.0	1.4	2.1	2.5	-0.1	0.9	1.2	0.6
26	1.8	2.1	3.1	3.0	0.3	0.6	1.4	1.6
28	1.8	1.5	2.8	3.2	0.3	1.0	1.1	0.2

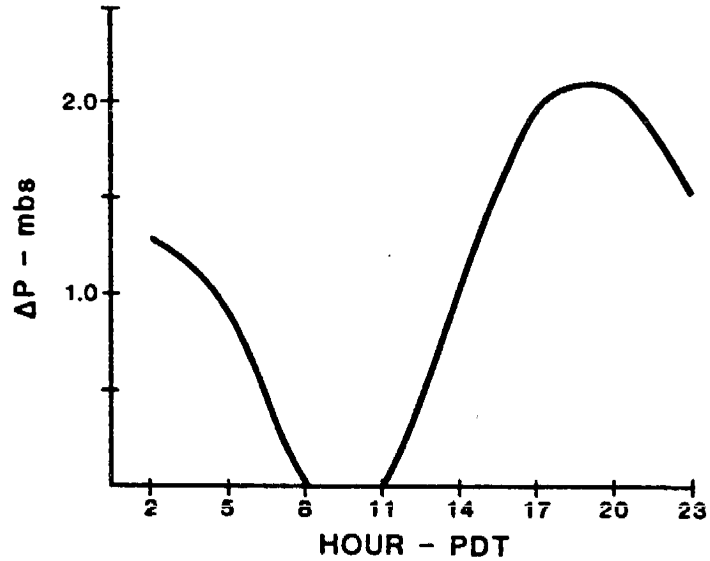


Figure 2.4.1 Diurnal Variation in SAC-RBL Pressure Gradient. 9-28 August 1980.

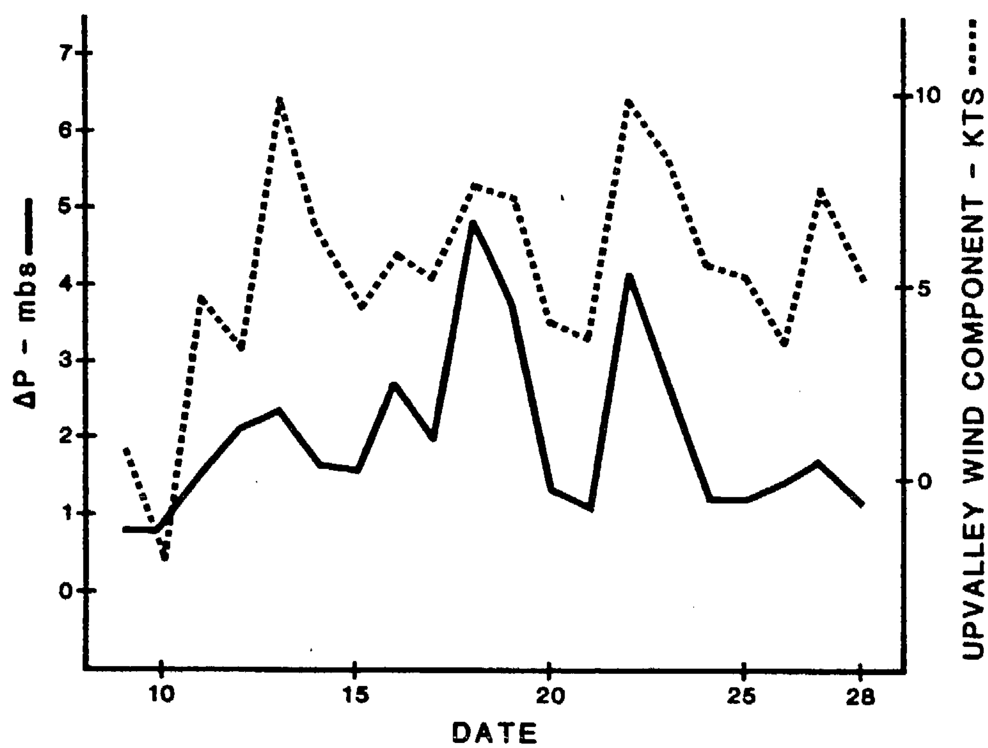


Figure 2.4.2 1700 PDT SAC-RBL Pressure Gradient (solid line) and 1700 PDT Upvalley Wind Component at Sacramento (broken line). For period 9-28 August 1980.

850 mb Temperature

Other studies have shown the 850 mb level to be a simple indicator of the regional air pollution potential. Warm temperatures aloft are typically associated with stable atmospheric conditions which tend to trap pollutants in the lower layers. Low temperatures, on the other hand, are usually indicative of synoptic disturbances which act to, at the very least, decrease atmospheric stability.

Figure 2.4.3 shows the daily variation of the 05 PDT temperature at 850 mb for Oakland during the study period. The long-term average (1956-1980) is also shown in the figure. On 12 August a major change in the long wave weather pattern was developing which persisted for the remainder of the study. The transition from ridging aloft and above normal temperatures early in the month into a pattern which brought a series of short-wave troughs through the study area and unseasonably cool air is clearly apparent from the figure.

Test 1 was the only one conducted under above normal conditions as intense warming was reaching a maximum and the flow was beginning to stagnate within the Valley. The second test was conducted during the transition period just prior to the passage of the first of the series of upper-air disturbances on the 14th. Tests 3 and 5 were conducted during brief stabilizing periods between trough passages. Although conditions during Test 4 provided good transport winds from the Bay Area into the Sacramento Valley, the presence of a weather system just offshore caused widespread cloudiness and isolated showers. Insolation was kept to a minimum during the test and pollution levels were low. Test 6 was also conducted under deteriorating weather conditions. However, again the flow for which the test was designed did develop; specifically a morning eddy existed in the southern Valley.

Surface Temperature

Ambient surface temperature is an indicator of potential ozone production as reaction rates are dependent upon insolation and heating. According to Keifer (1977), threshold for initiation of significant ozone generation is about 78^{0}F with an exponential increase in the reactive process as temperature increases. The maximum daily temperature at McClellan Air Force Base, just outside of Sacramento, is shown for the study period in Figure 2.4.4. As expected, the data show a similar trend to the 850 mb data.

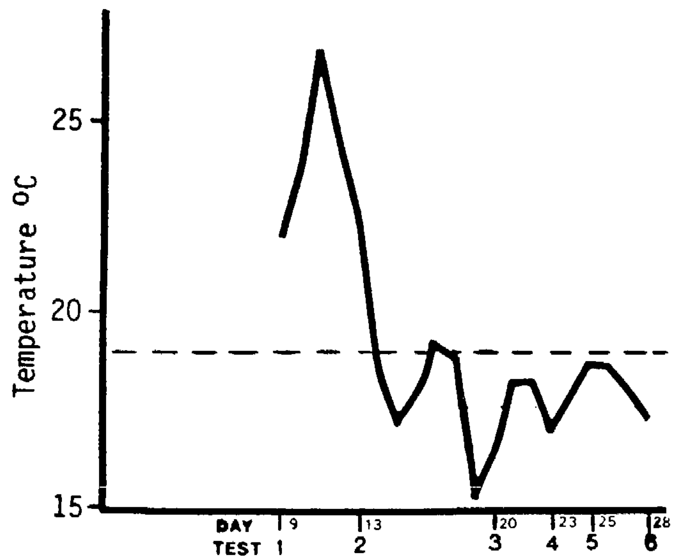


Figure 2.4.3 850 mb Temperature from Oakland - August 1980
Dashed line is August Average 1976-1979.

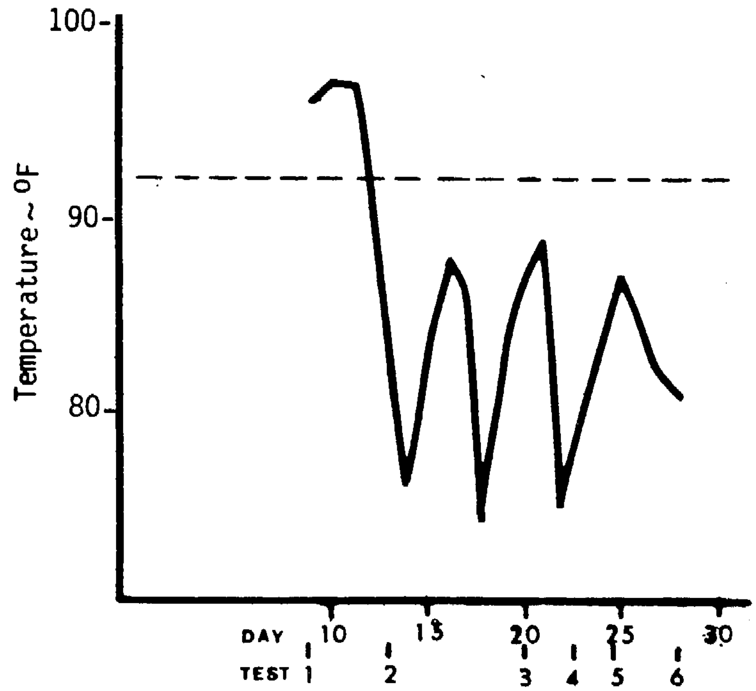


Figure 2.4.4 Maximum Surface Temperature at McClellan AFB-August 1980
(Dashed line is August mean of record.)

With the exception of the first test, all the tests were conducted while temperatures were less than the long-term mean. Surface temperature reported during Tests 2, 4, and 6 suggest only minimal ozone production processes were active.

Mixing Layer Height

The height of the mixing layer is critical in evaluating transport and dilution of pollutants within the flow. The data from airsondes provide a continuous temperature-height profile and were typically released every six hours during tracer tests. Maximum afternoon mixing heights were estimated from the airsonde data and maximum daily surface temperature using the method described by Holzworth (1972). Estimates by this method are summarized in Table 2.4.3. Maximum mixing heights in the Valley ranged from 500 to 1300 m. The median value was 750 m.

The depth of mixing can be determined directly from the soundings taken by the MRI sampling airplane. These soundings give a continuous reading of temperature, turbulence, and b_{scat} in addition to gaseous pollutants. From consideration of these parameters, the afternoon mixing heights are shown in Table 2.4.4. From the table it can be seen that in the Valley, mixing ranged from 450 to 950 m; the median value being 550 m. In the foothills, mixing ranged from 550-1050 m with 850 m the median value.

The data in Tables 2.4.3 and 2.4.4 are in good agreement; suggesting the Valley has a rather uniform mixing layer depth.

Table 2.4.5 summarizes the depth of the mixing layer measured by the acoustic radar at Georgetown in the Sierra Nevada foothills. In this table, the mixing depth is defined to be that region from the surface to either a thermal or wind discontinuity. Night and early morning depths were typically less than 40 m or below the minimum detection height. By noon the mixing depth on most days had exceeded the maximum instrument range of 1000 m. This condition continued throughout the afternoon. This suggests that the nocturnal inversion at that location is very shallow and as a consequence erodes quickly as the surface heats allowing mixing to extend through a deep layer early in the day.

Table 2.4.3. Maximum Mixing Layer Heights (m) as Determined from Airsonde Data.

Date	Sacramento	Woodland
8/9	500	
8/10	700	
8/13	500	
8/14	800	
8/20	1300	
8/21	1100	
8/23	750	
8/24	800	
8/25	500	
8/26	750	
8/28		500

Table 2.4.4. Mixing Layer Heights (m) from Aircraft Soundings

Time(PDT)	8/9	8/13	8/20	8/21	8/23	8/25
			SACRAMENTO VALLEY			
14	680			850		550
	450					
15	570	510	1000			
17		530	800		550	
			FOOTHILL REGION			
15						1050
16						1050
17		550				1050
18			850			
			750			

Table 2.4.5 Acoustic Radar Mixing Layer Depths
12 August - 29 August 1980
Georgetown

Time (PDT)	Median Depth (m)	1/4 of Observations Exceeded (m)
0600	<40	<40
0900	140	300
1200	>1000	>1000
1500	>1000	>1000

3. Regional Air Quality

The following sections describe the air quality during August 1980; the period in which the field study was conducted. Air quality is discussed in terms of ozone or oxidant as this secondary pollutant has previously been identified as the major contributor to deleterious air quality in the Sacramento Valley Air Basin as in other regions of California. Ozone concentrations measured at both existing long-term monitoring sites and the sites established expressly for this study are selectively discussed. A discussion based on aircraft sampling of the initial Sacramento urban plume prior to significant photochemical activity is included.

3.1 An Overview of the Air Quality During the Study

As discussed in Section 2, a cool weather pattern persisted in Northern California during the latter part of August which resulted in periods of atmospheric instability and widespread cloudiness. Since ozone production is dependent upon insolation and ambient temperature the oxidant experience in the Sacramento Valley should be reduced during this period. On Table 3.1.1 the number of days and hours on which hourly-averaged ozone concentrations equaled or exceeded the California State standard (10 pphm) are tabulated and compared with 1978 and 1979. In the Sacramento area, considering the data scatter, the number of days in 1980 on which the standard was equaled or exceeded are comparable to the two previous years. The number of hours, however, was significantly less than in 1978 but comparable to 1979. Unfortunately concurrent data were not available for the receptor locations, Folsom and Auburn. Woodland shows a marked decrease in ozone experience during 1980 when compared with the prior two years but Redding shows a marked increase in the number of days column. Overall, within the southern region of the Valley, 1980 shows a similarity in ozone events with 1979 but a marked decrease in the hours on which the standard was equaled or exceeded when compared with 1979. On the other hand, Redding, the only northern Valley monitoring site with a long-term record, was seemingly impacted more than in the other years. This may be due in part to the choice of criteria as shown below.

Table 3.1.1 August Ozone Summary

Station	No. of days ≥ 10 pphm 1978	1979	1980	No. of hours ≥ 10 pphm 1978	1979	1980
Woodland	12	8	4	56	27	8
Sac/Creekside	11	7	9	46	29	21
Sac/P St.	8	5	4	34	13	5
Rocklin	17	8*	14	110	42*	52
Folsom	14	13	-	58	63	-
Auburn	-	**	19	-	**	78
Redding	4	4	8	21	14	24

* 6 days data missing
**20 days data missing

Source: CARB Annual Air Quality Data Summary

Daily maximum hourly-averaged concentrations for selected sites in the Sacramento Valley are shown in Figure 3.1.1 and for the project sites in Figure 3.1.2. The geographic location of the sites are shown in Figure 3.1.3. Redding, it is interesting to note, experienced no exceedances greater than 10 pphm. Sacramento, Citrus Heights (approximately halfway between downtown Sacramento and Auburn), and Placerville all show numerous exceedances of the State standard. The remaining three mountain sites (White Cloud, Foresthill, Georgetown) all show instances at least equaling the State standard. The highest concentration at any location was reported on 11 August at Citrus Heights (15 pphm). All locations show a trend towards decreased ozone concentrations in the latter half of August. As discussed in Section 2, on 11 August the general circulation shifted into a pattern which would persist the remainder of the month and bring into the area a series of weather systems. These conditions led to unseasonably cool temperatures and often widespread cloudiness. This turn of events is clearly reflected in the ozone data.

The plots on Figures 3.1.1 and 3.1.2 are annotated with the test schedule. Tests 1 (9 August), 3 (20 August), and 5 (25 August) were conducted under stabilizing meteorological conditions which coincided with regional ozone peaks. Auburn maximum ozone concentrations exceeded 10 pphm during each of those tests. On the other hand, the remainder of the tests were conducted during periods which were unfavorable for high ozone production.

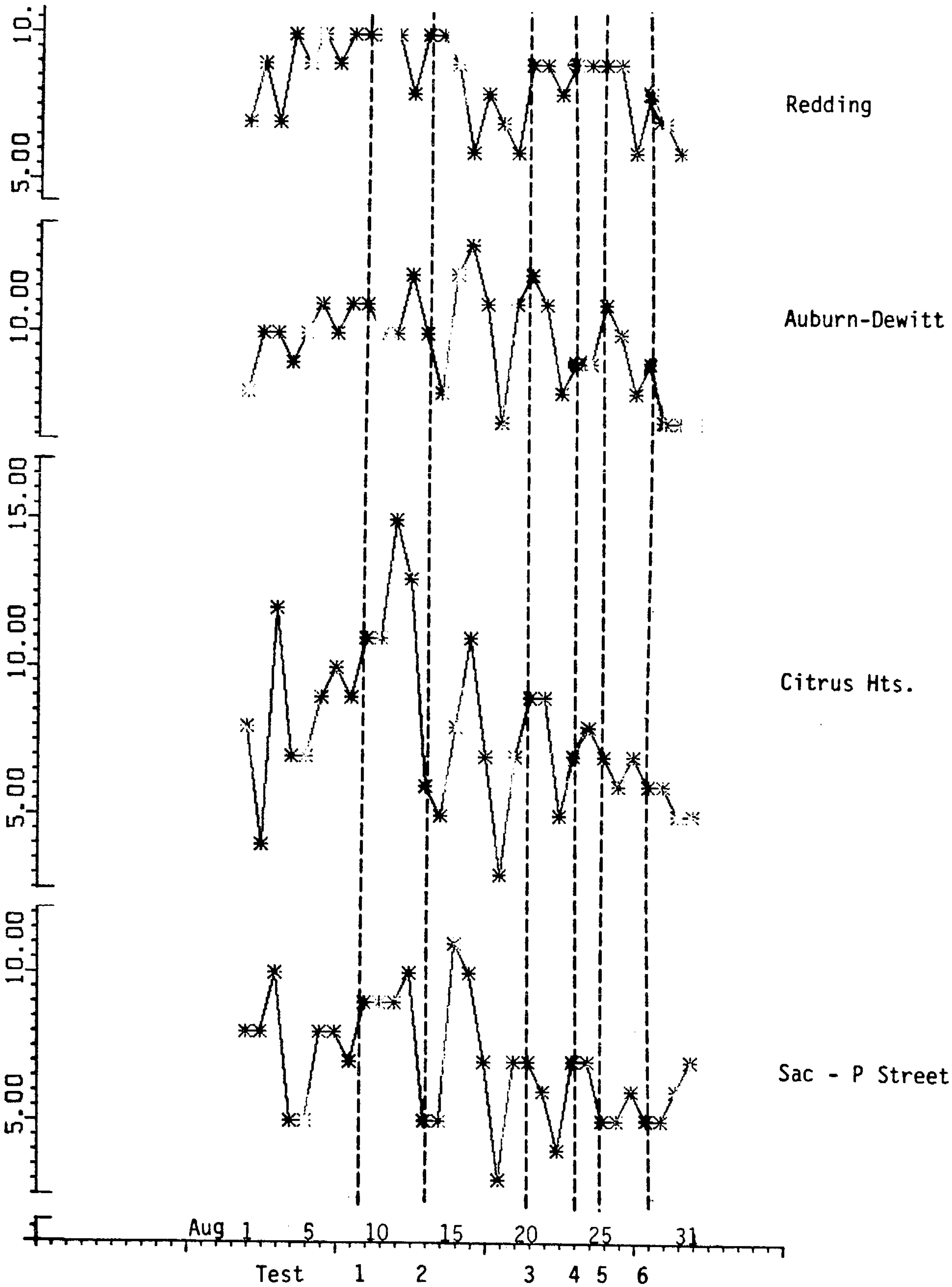


Figure 3.1.1 Maximum Daily Ozone (pphm) for Selected Monitoring Sites within the Sacramento Valley. August 1980. Dashed vertical lines show test days.

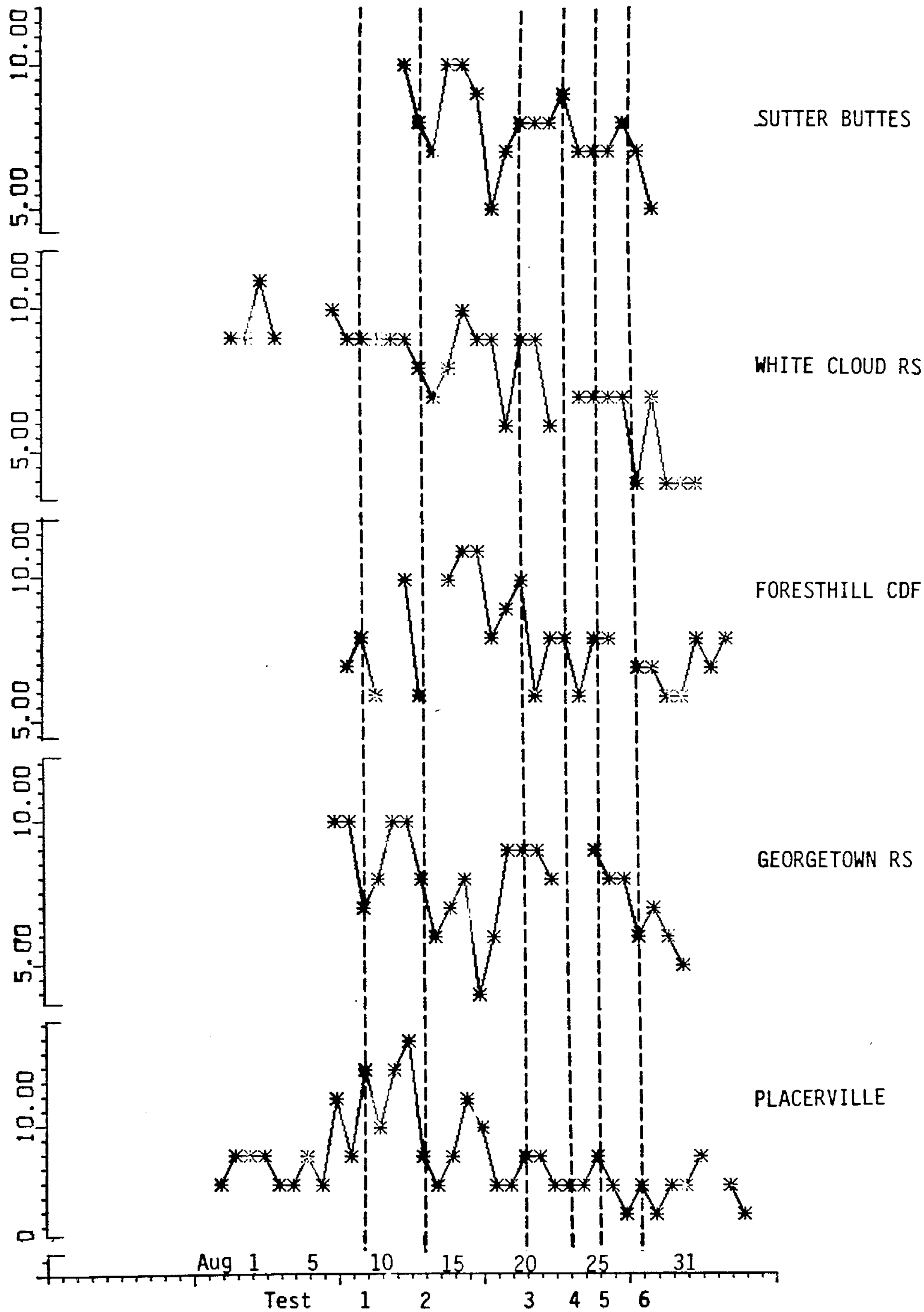


Figure 3.1.2 Maximum Daily Ozone (pphm) for Project Monitoring Sites. August 1980. Dashed vertical lines show test days.

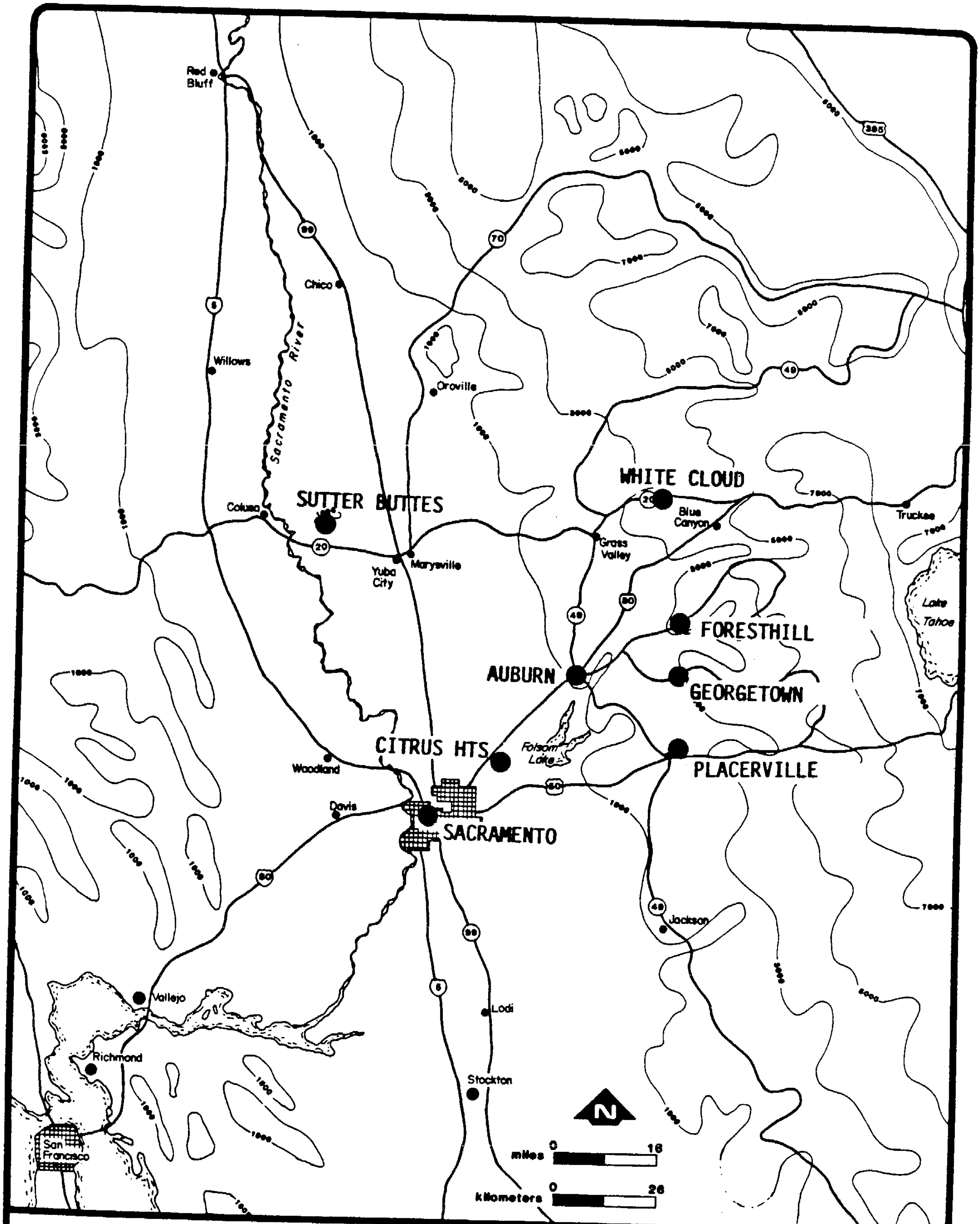


Figure 3.1.3 Locations of the Air Quality Data Shown in Figure 3.1.1 and 3.1.2.

3.2 Diurnal Variation of Ozone

Williams (1973) and others have described the genesis of photochemical smog in urban regions and the formation of the secondary pollutant, ozone. Early in the morning as commuter traffic increases, the ambient concentrations of NO and hydrocarbons begin to rise. After sunrise, as photochemical processes in the atmosphere become active, oxides of nitrogen and hydrocarbons react in such a way as to produce a strongly oxidizing atmosphere in which ozone builds up quickly. During later hours, increases in solar flux and temperature increase the rate of photochemical processes. As the smog matures, hydrocarbons and nitrogen dioxide are removed by chemical side reactions which yield secondary pollutants such as ozone and aerosols. The aerosols are a major cause of the reduction of visibility. Ozone does not persist in high concentrations in the surface air layer. It is typically "scavenged" by reacting with the ground surface, plant surfaces and chemicals in the atmosphere. Thus towards the end of the day, as the intensity of solar radiation diminishes, the ozone concentration also decreases in the surface mixing layer where the air/surface interface occurs.

The major source region in the Sacramento Valley is the Sacramento urban area (Duckworth and Crowe, 1979; Giorgis, 1980). Figure 3.2.1 shows the mean diurnal ozone concentration from a monitoring location within the urban area. The figure shows the characteristic features described above; i.e. maximum concentrations occurring near the time of maximum insolation and minimum concentrations due to scavenging during the night. Superimposed upon the ozone formation process are local wind flows. Typically, unless stagnation of the air mass occurs, the smog drifts downwind such that the higher levels of ozone experienced when the smog is mature impact areas other than at the source. This effect is shown in the Citrus Heights and Placerville data presented on Figure 3.2.2 and 3.2.3 respectively. The Citrus Heights data, from a suburb east of the central metropolitan area, shows a later and increased ozone peak relative to Sacramento-Creekside, reflecting the urban plume transport. Some ozone depletion is evident at night but is markedly less than the Sacramento data show. As the plume continues to drift downwind towards Placerville, in the Sierra foothills, two distinct peaks are reflected in the ozone curve of Figure 3.2.3. The earlier peak represents the generation of ozone from local sources but the second is apparently the impact of the Sacramento urban plume. The later peak, which is greater in magnitude than both

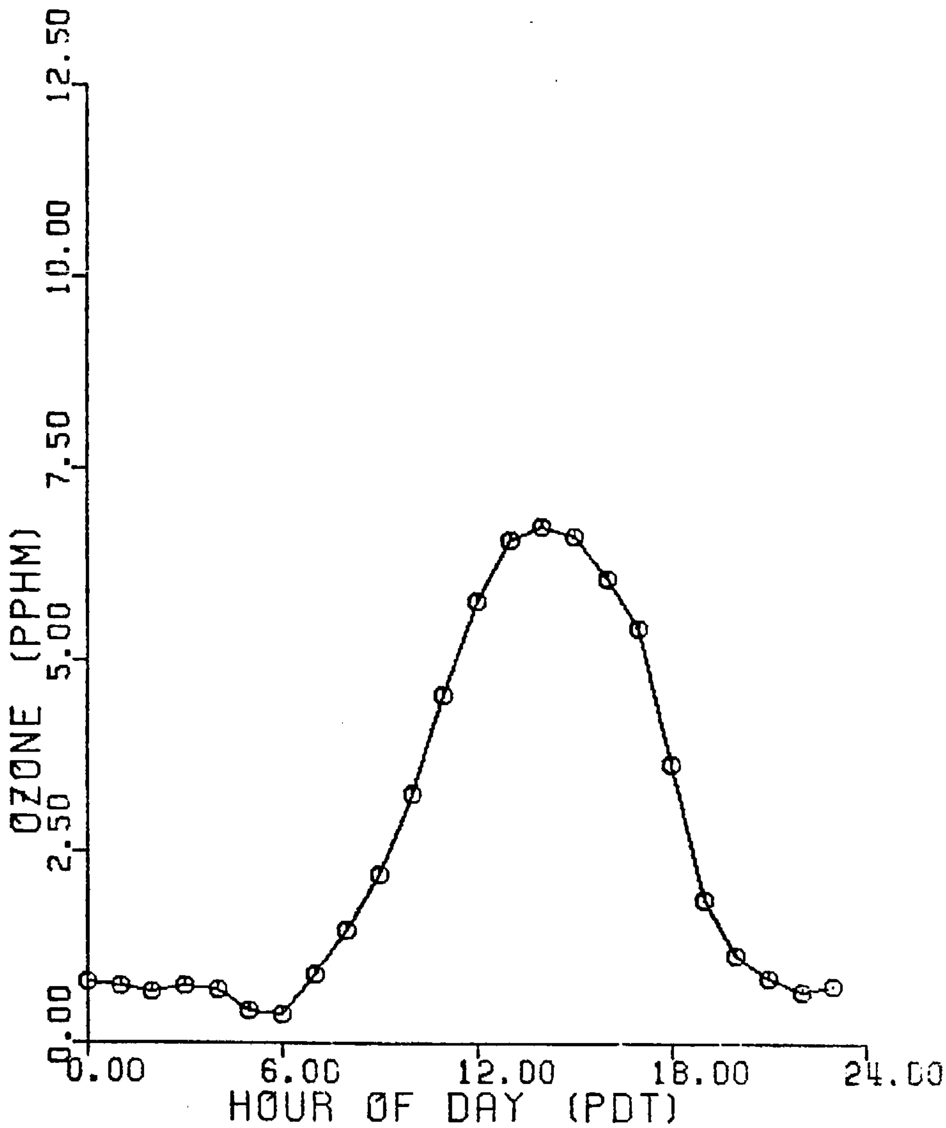


Figure 3.2.1 Monthly Mean Hourly Averaged Concentration of Ozone during August 1980 at Sacramento-Creekside.

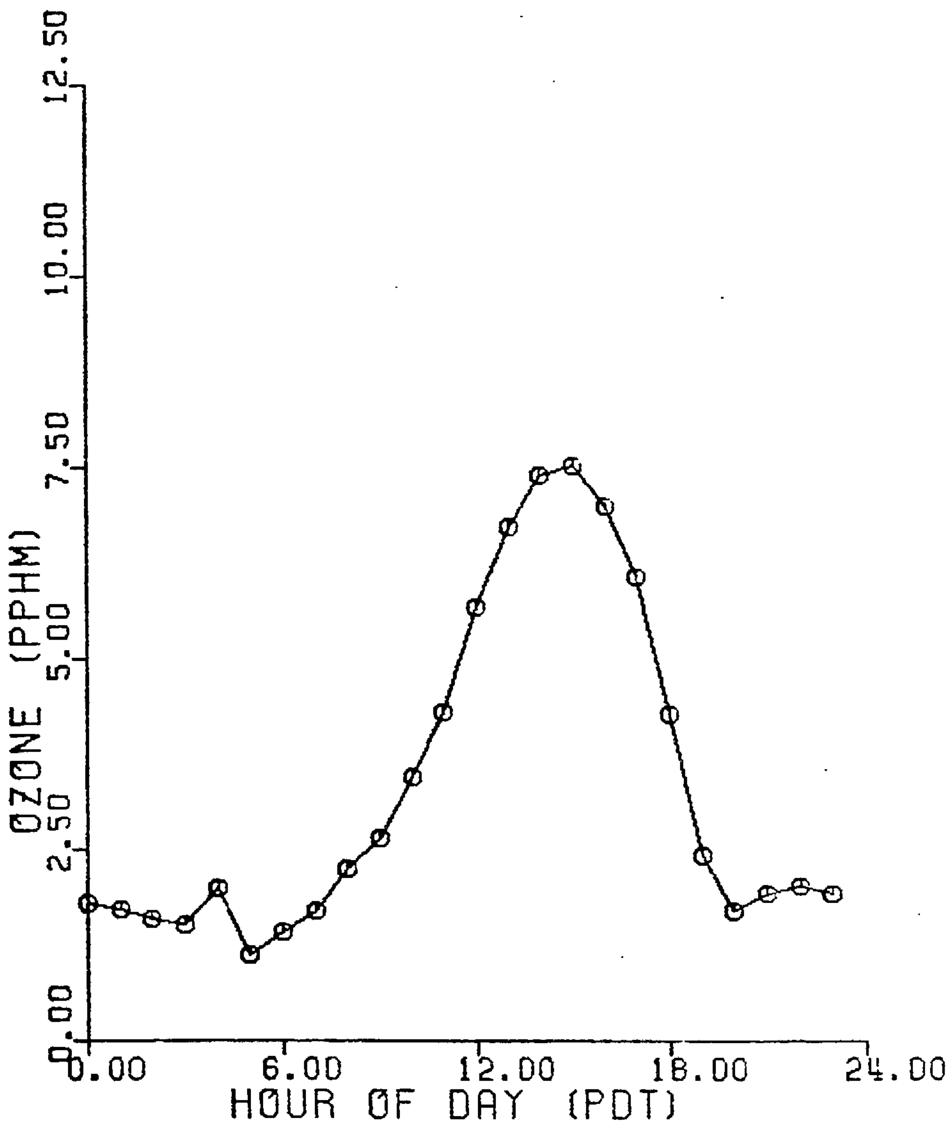


Figure 3.2.2 Monthly Mean Hourly Averaged Concentration of Ozone during August 1980 at Citrus Heights

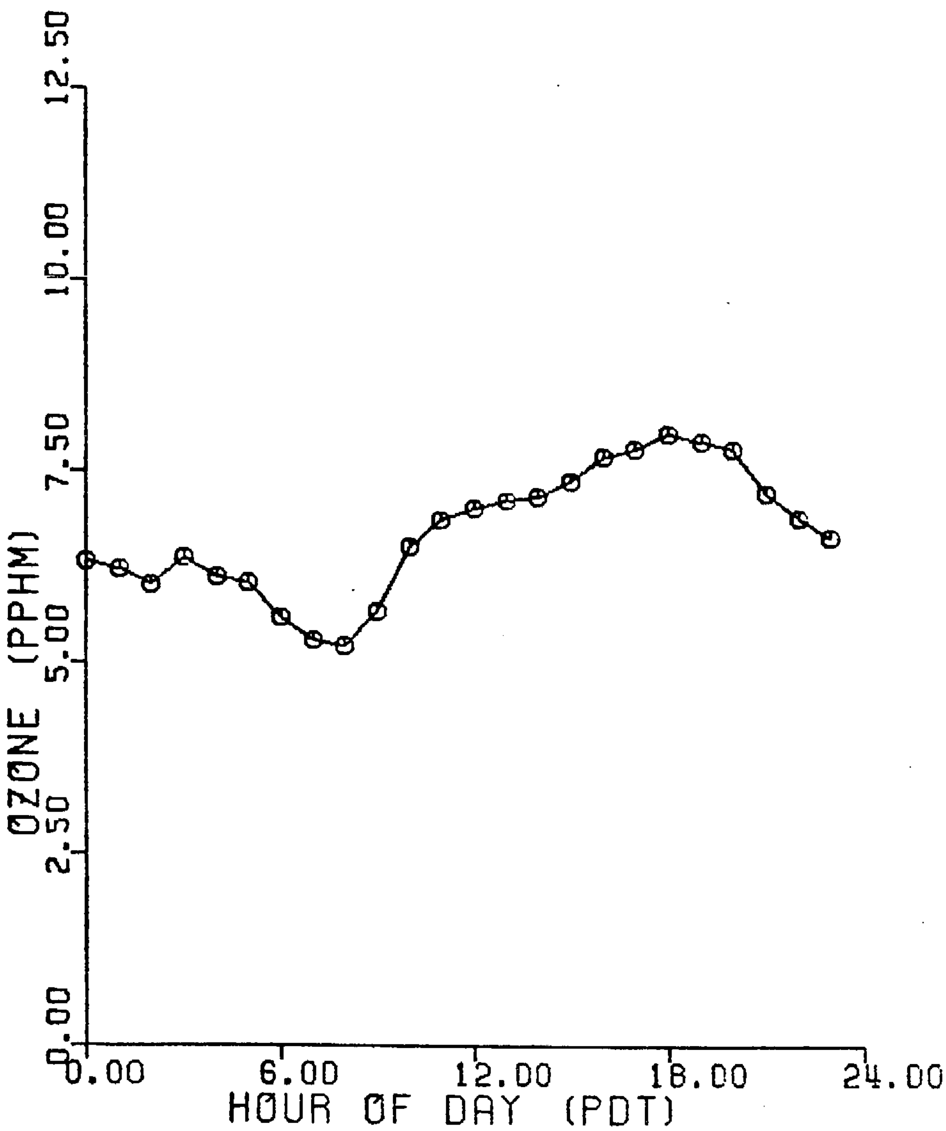


Figure 3.2.3 Monthly Mean Hourly Averaged Concentration of Ozone during August 1980 at Placerville.

Sacramento or Citrus Heights, occurs at 1800 PDT or some 6 hours later than in Sacramento. This would suggest a mean transport speed of about 2.5 m/s which agrees with the Sacramento area winds discussed in Section 2. Note the decreased ozone scavenging at night. Minimum concentrations, observed shortly after daybreak, are roughly what one might expect for background ambient levels.

The Redding ozone data show a different diurnal pattern. The mean hourly-averaged ozone concentrations are shown on Figure 3.2.4 and a statistical breakdown of the data is given on Figure 3.2.5. From the figures it is seen that maximum concentrations are measured from 10-1700 PDT. For comparison, a similar statistical breakdown of hourly concentrations in the Sacramento urban area is shown on Figure 3.2.6. The data clearly show that maximum ozone concentrations within the source region are an early afternoon phenomenon. The relatively early maxima at Redding may be the result of fumigation of an old elevated ozone plume as the mixing layer deepens. Possible sources of ozone transported to the northern regions of the Valley will be discussed in following sections of this report.

The Sutter Buttes ozone data show an unusual diurnal trend. On Figure 3.2.7, the mean hourly-averaged concentrations for that site are shown. Unlike the curves from the other locations, which show minimum levels shortly after daybreak with increasing ozone as insolation increases, the data from Sutter Buttes show a minimum between 1000-1200 hours. A close examination of the record revealed that this was the case on each day over the sampling period with only one exception. This site is unique in that it was located at the highest point of an obtrusive topographic feature which abruptly rises to over 2000 feet above an otherwise flat Valley floor. At this elevation, it is above the Valley surface nocturnal inversion and thus is decoupled from the air in contact with the surface but may be within the mixed air layer later in the day. Although there might be some small scale slope effects, the air being sampled may be representative of the free atmosphere at 2000 ft. During stable conditions, variations in ozone concentrations would be due to advection. The wind data from Sutter Buttes (Figure 2.2.3) during the 7-12 PDT period, unlike the remainder of the time, show a preference for northeast flow. The ozone minimum corresponds to the period with the northeast flow.

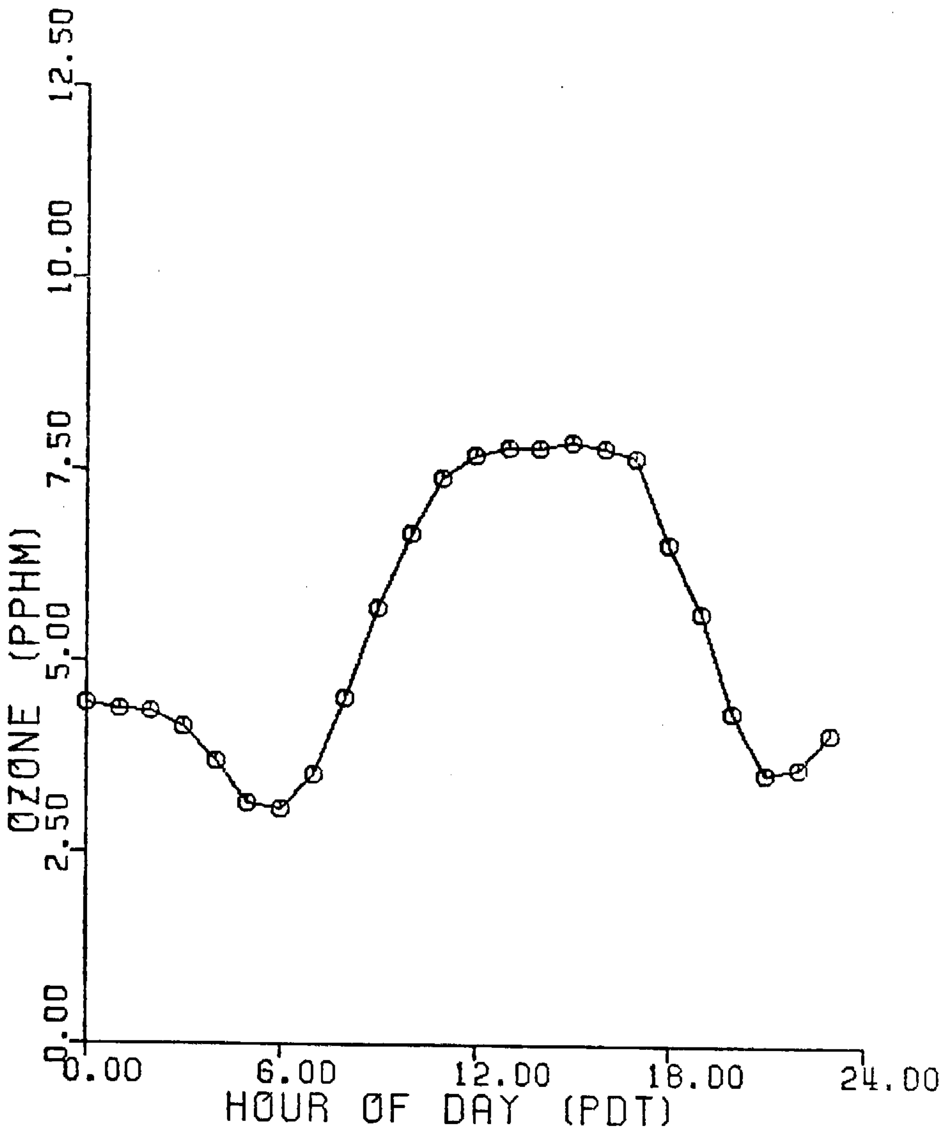


Figure 3.2.4 Monthly Mean Hourly Averaged Concentration of Ozone during August 1980 at Redding.

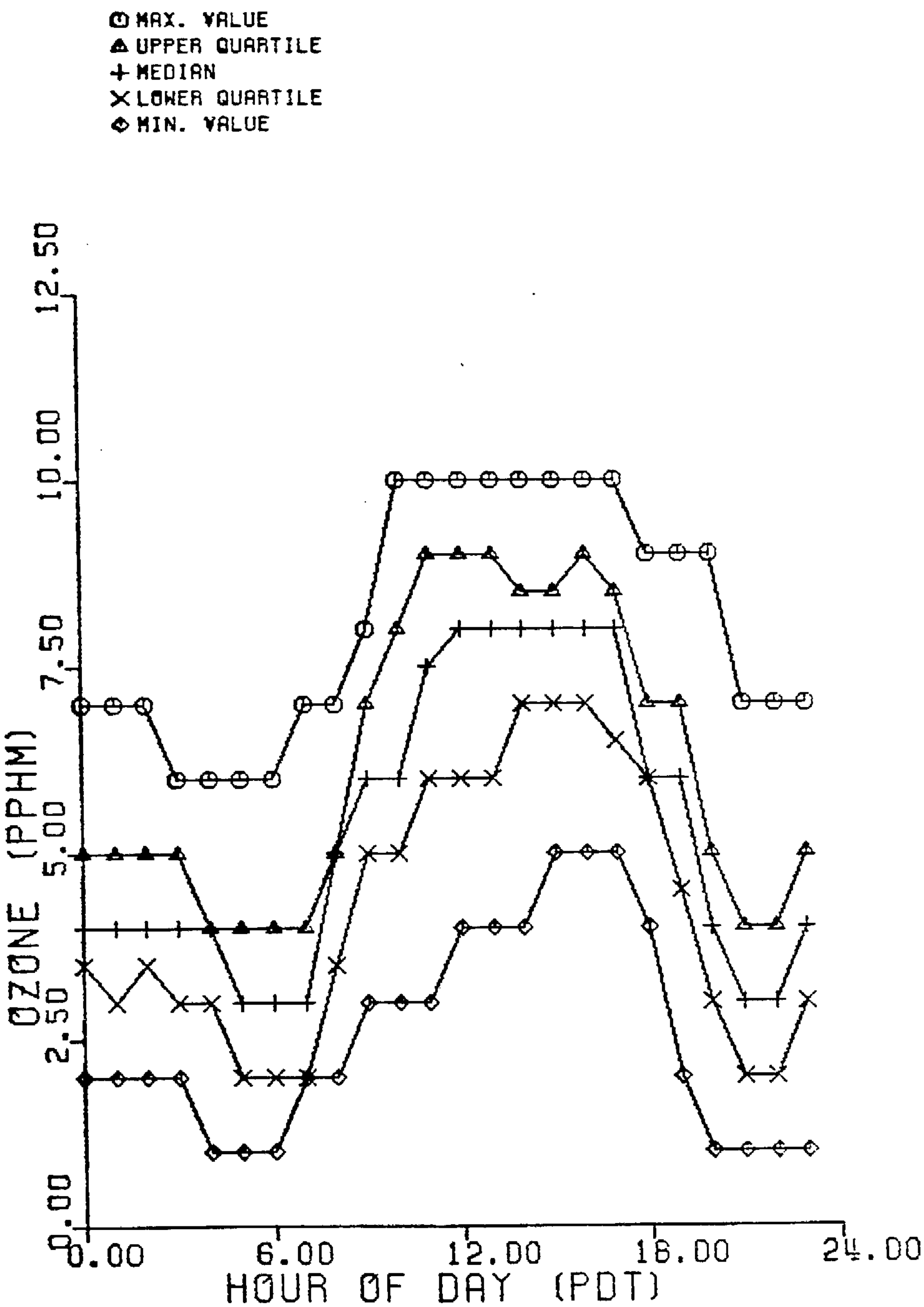


Figure 3.2.5 Statistics of Hourly Averaged Concentration of Ozone during August 1980 at Redding.

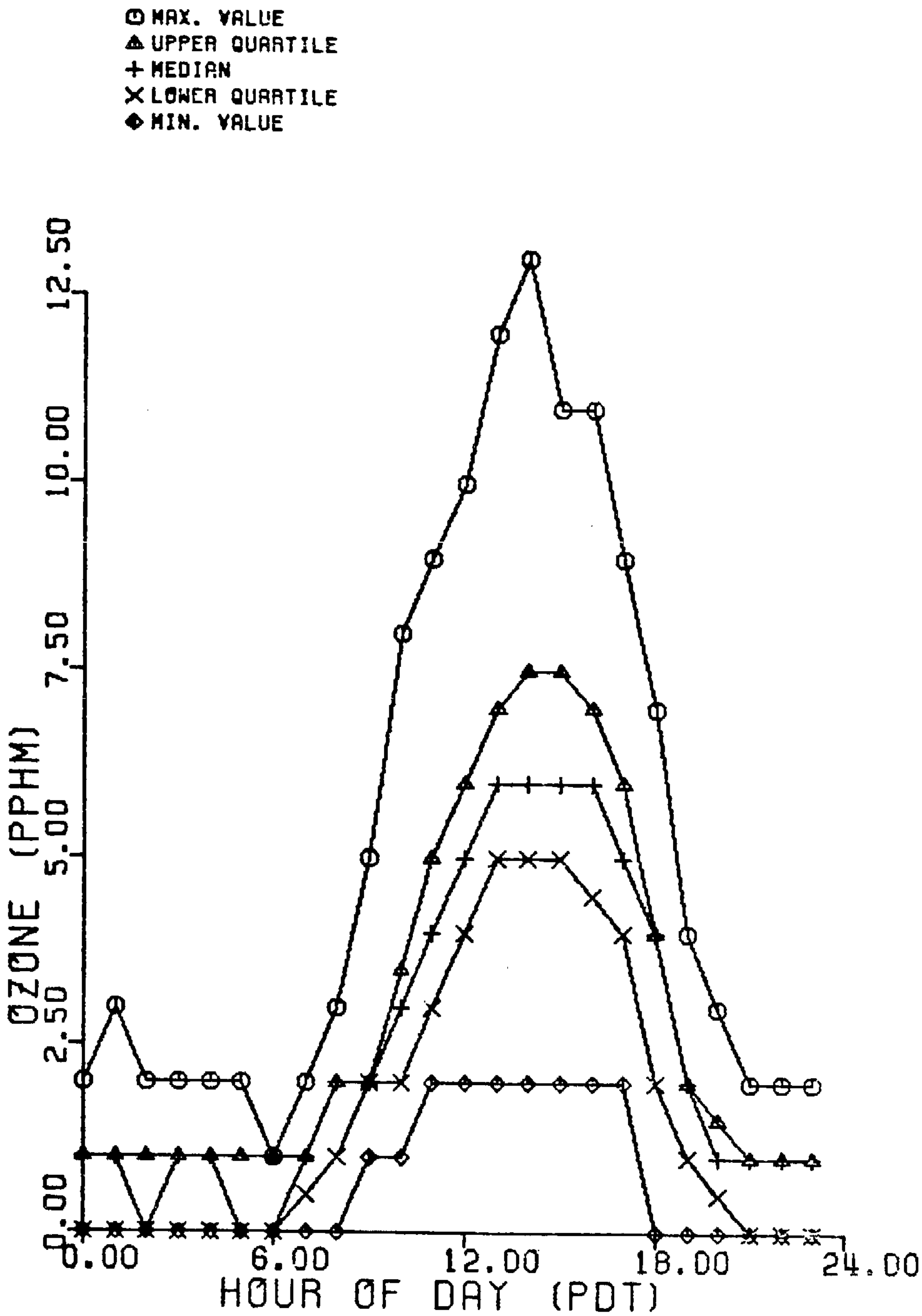


Figure 3.2.6 Statistics of Hourly Averaged Concentration of Ozone during August 1980 at Sacramento-Creekside.

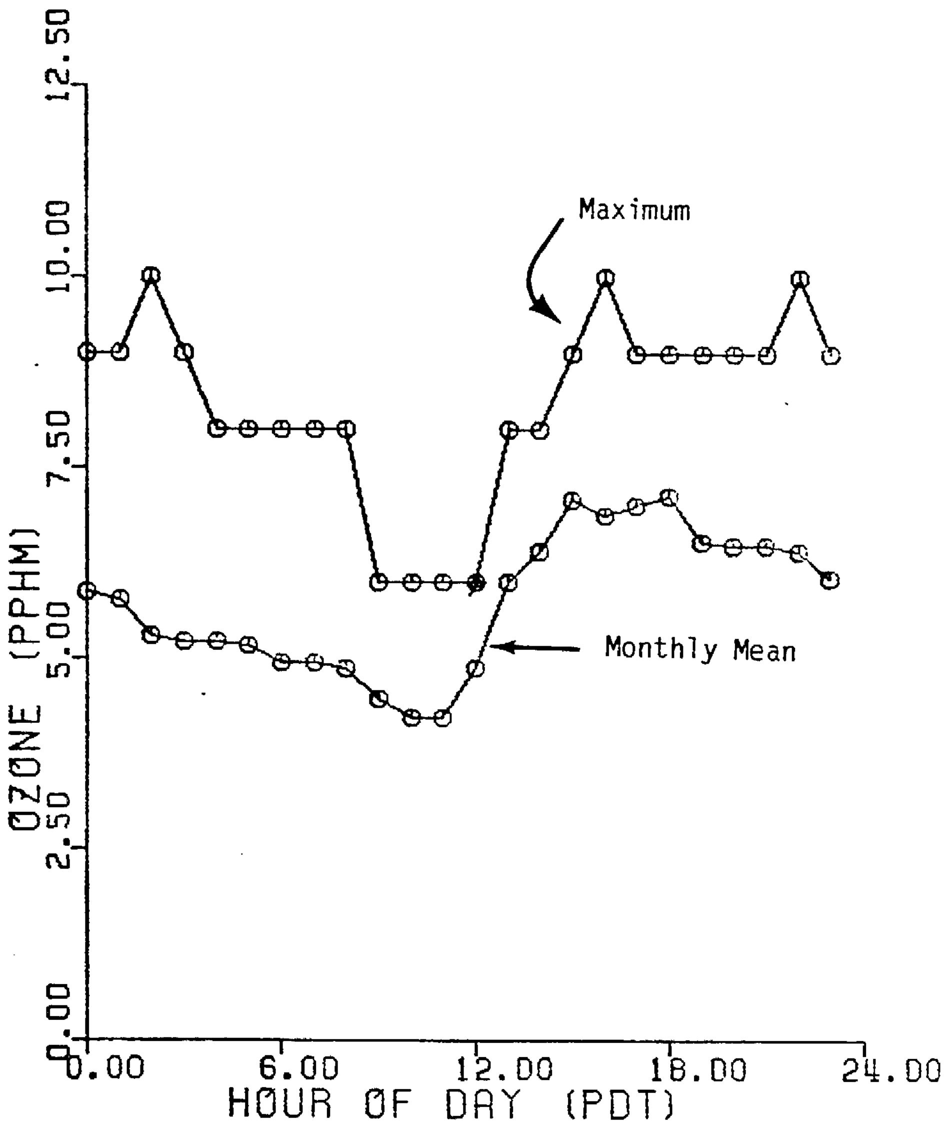


Figure 3.2.7 Hourly Averaged Concentration of Ozone during August 1980 at Sutter Buttes.

3.3 Morning Inversion and Air Quality Characteristics in the Sacramento Area

On three mornings during the field study, the MRI Cessna 206 airplane sampled in the Sacramento area; the major oxidant source within the Sacramento air basin. Each flight consisted of 2-3 spirals at locations both upwind of the prevailing surface flow and within the urban area. The airplane began sampling shortly after sunrise each day such that initial conditions before photochemical processes became active and pollution accumulation under the nocturnal inversion could be observed. Air quality, meteorological, and position parameters listed in Table 3.3.1 were recorded at the rate of once per second on computer-compatible tape.

Figures 3.3.1 through 3.3.3 show an example of an early morning sounding at an urban location. The set of aircraft soundings are summarized in Table 3.3.2. Information about the inversion characteristics, pollution burden beneath the inversion, and elevated ozone layers are contained therein. The location of the soundings are shown on Figure 3.3.4. The Sacramento VOR and the Sunset Skyranch airport represent locations generally upwind of the urban sources. The Rio Linda and Phoenix (Fair Oaks) airports are within the urban influence.

From the table it is seen that inversion strength or magnitude varied considerably between the three days. Lorenzen (1979) summarizing 6 years of Sacramento inversion statistics showed that 68% of the inversions occurring in the summer months had magnitudes of between 7-13^{o}C while only 4 out of 514 cases had magnitudes equal to or greater than 17^{o}C. By comparison, two of the three days sampled in this study showed inversion magnitudes outside the 7-13^{o}C range. Mixing depth was determined from a consideration of turbulence and the pollutant profiles. They appeared to be rather uniform spatially and from day to day, ranging from 100-250 m. Although the urban soundings always showed an increase in NO_x concentration, levels were generally low. This could be attributed to the moderate transport winds which generally occur during the night thus precluding the accumulation of fresh emissions within the source area. Good agreement was found between the airplane data and the downtown surface monitoring site on the 13th and 25th. On the morning of the 20th, accumulations of NO_x in the range 3-6 pphm were measured at the surface as compared to the 1 pphm levels measured by the aircraft. An interesting feature of the data is the repeated occurrence of

Table 3.3.1

MRI CESSNA 206 INSTRUMENT CONFIGURATION

- Sulfur Dioxide - Meloy 285 E
- Ozone - Bendix
- Oxides of Nitrogen - Monitor Labs 8440
- Integrating Nephelometer - MRI Model 1550
- Temperature - MRI Vortex-Housed Thermister
- Dew Point - Cambridge Systems 137
- Turbulence - MRI 1120 UITS
- Altitude, Indicated Airspeed - Validyne Pressure Transducers and Pitot Static Probe
- Position - Aircraft VOR/DME
- Data System - LSI 11 Computer System. One scan per sec logged on a DecTape II data cartridge recorder
- Chart Recorder - Linear Instruments Model #486 (2-channel)

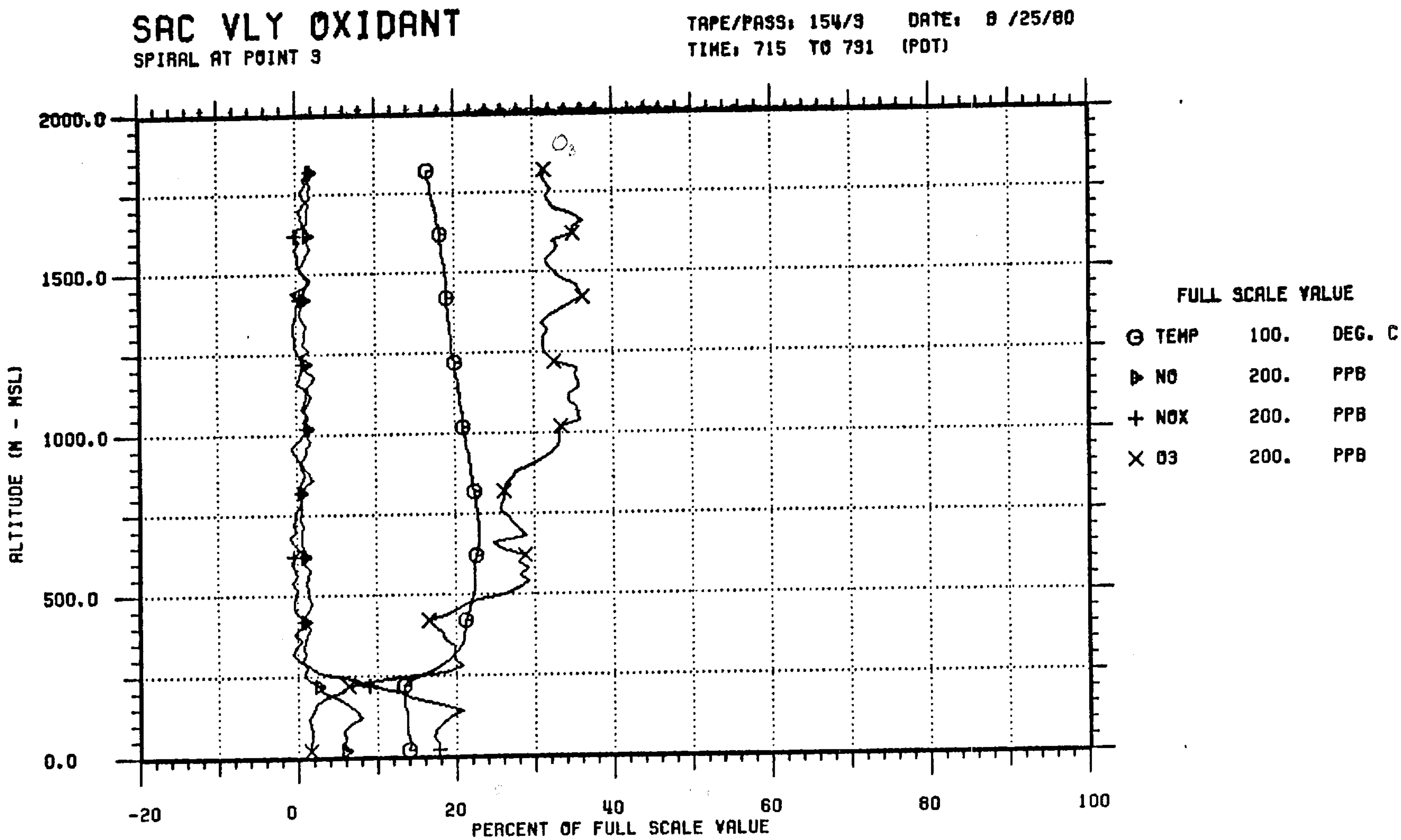


Figure 3.3.1 Morning Aircraft Sounding Over Rio Linda Airport. 25 August 1980. Showing Temperature, Oxides of Nitrogen, and Ozone.

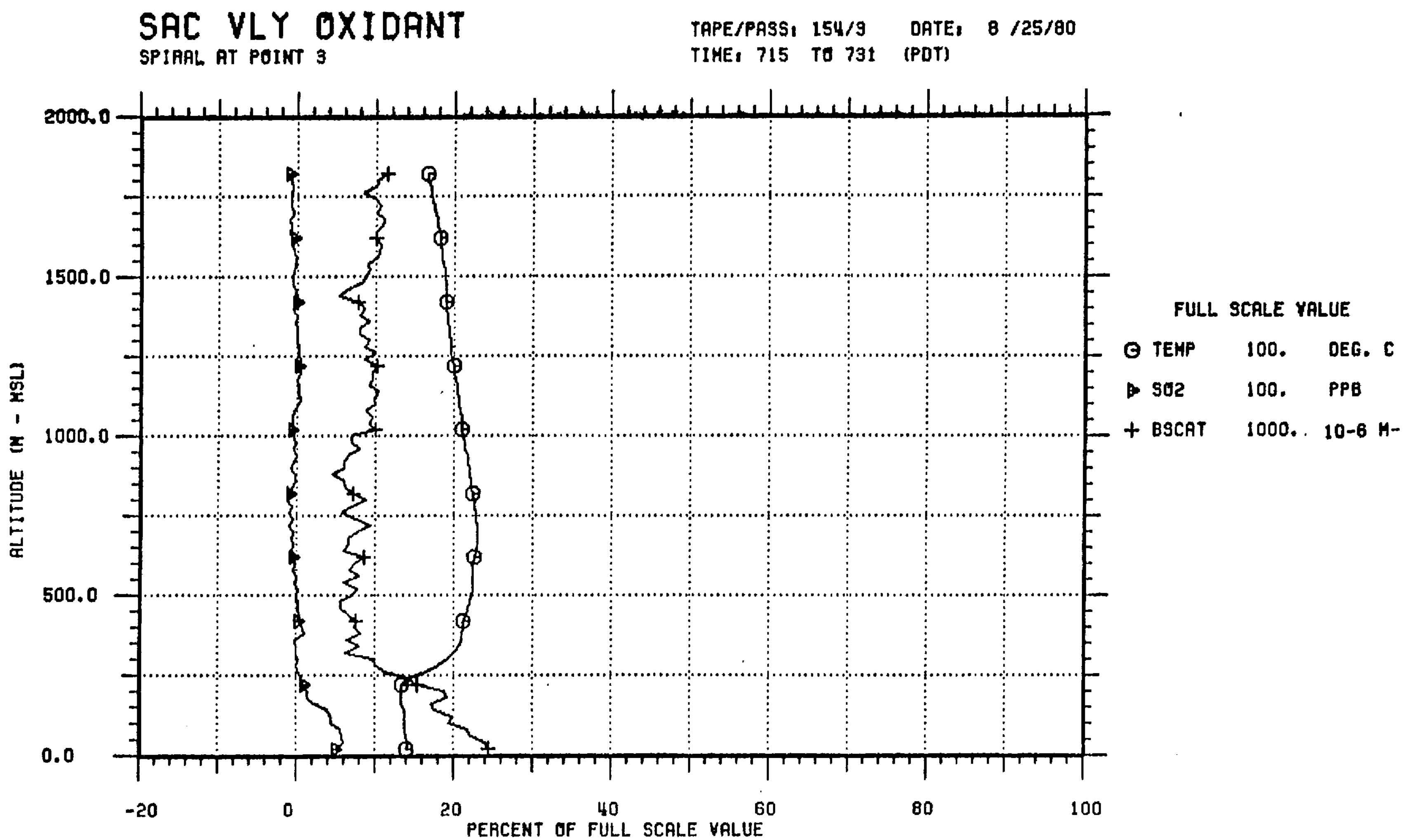


Figure 3.3.2 Morning Aircraft Sounding Over Rio Linda Airport. 25 August 1980. Showing Temperature, Sulfur Dioxide, and b_{scat}.

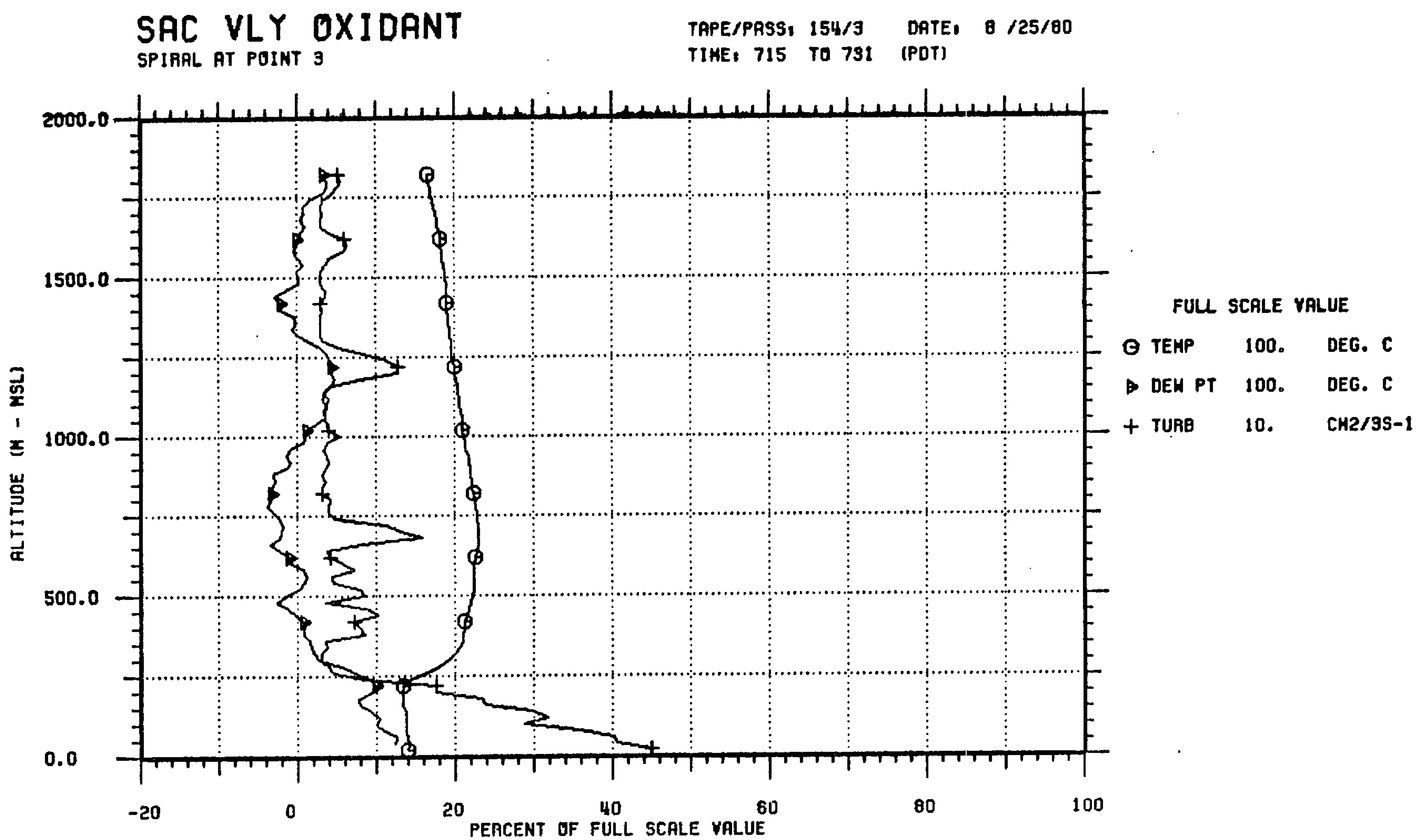


Figure 3.3.3 Morning Aircraft Sounding Over Rio Linda Airport. 25 August 1980. Showing Temperature, Dew Point, and Turbulence.

Table 3.3.2 Summary of Morning Aircraft Soundings Taken in the Sacramento Area.

	Inversion magnitude (^oC)	Inversion top (m-msl)	Mixing depth (m)	Ave Concentration (pphm) within mixing layer O_3	NO_x	SO_2	Max Ozone conc. (pphm)	Max Ozone height (m-msl)
8/13/80								
SAC VOR	17	700	200	2	1	0	9	1000
Rio Linda	12	800	100	1	3	0	9	1500
8/20/80								
Sunset Skyranch	5	900	250	2	0	1	9	900-1100
Rio Linda	6	600	250	2	1	0	9	850
8/25/80								
SAC VOR	11	600	200	2	0	0	8	1000-1600
Rio Linda	10	500	200	1	3	0	8	1000-1700
Fair Oaks	9	700	150	2	2	1	7	1700-1800

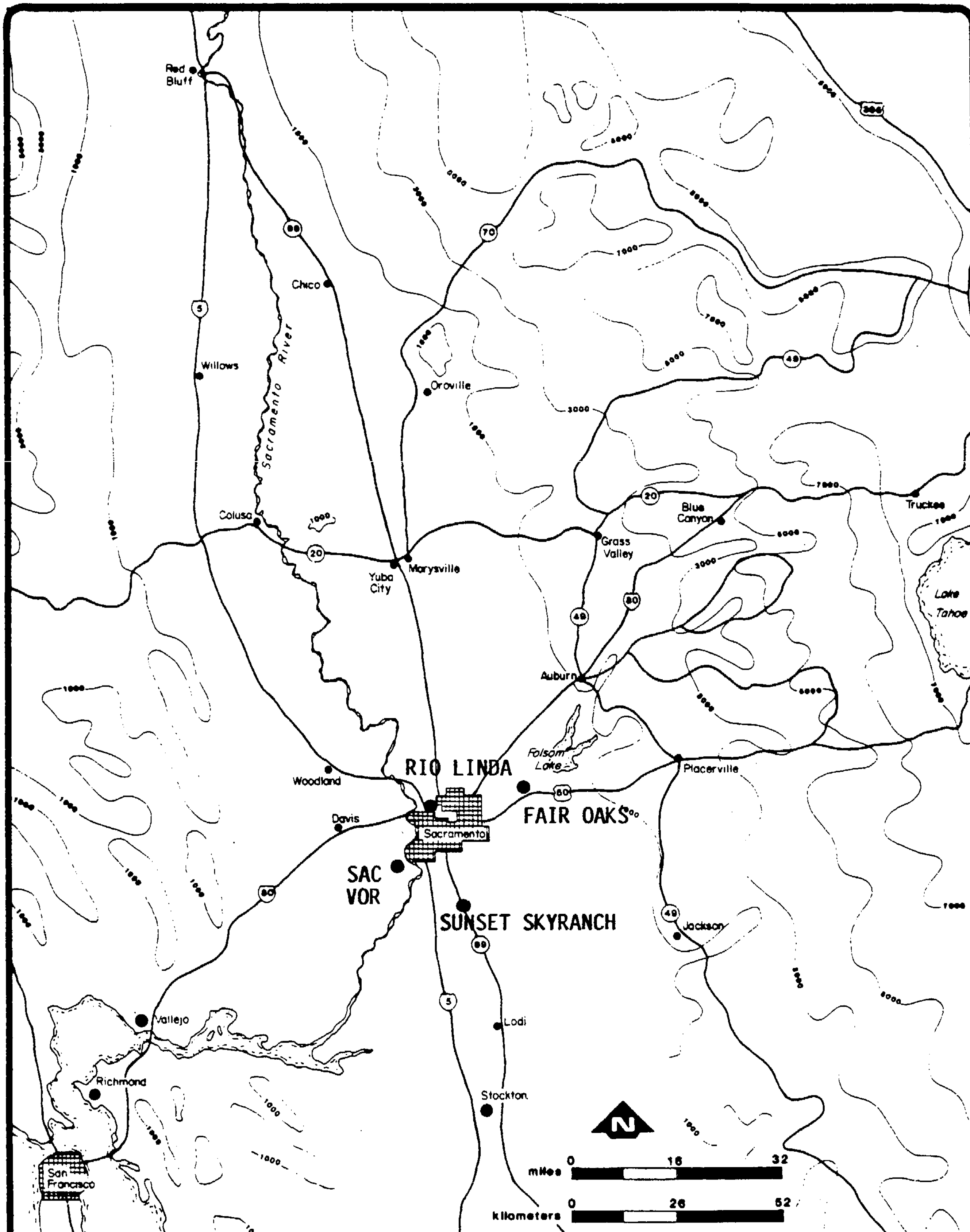


Figure 3.3.4 Location of Morning Aircraft Soundings

elevated ozone layers. Maximum concentrations are shown in the table to be spatially uniform. No general statement as to the source of this ozone aloft can be made at this time. On the 13th, pibal observations from Sacramento showed a northerly flow above 800 m while on the 25th a southerly flow was associated with the elevated ozone layer. No observations were available on the morning of the 20th.

4. Test Summaries

4.1 Test 1 9-10 August 1980, Vallejo Release (0620-1120 PDT)

4.1.1 Meteorology

General

The synoptic meteorology during this test was characterized at the surface by pressure ridging along the Pacific Coast and a thermal trough over the interior of California, resulting in a strong onshore pressure gradient (Figure 4.1.1). The warming and stabilizing of the atmosphere was reflected in the above normal 850 mb temperature over Oakland (Figure 2.4.3). Although a strong onshore pressure gradient existed, the gradient between Sacramento and Red Bluff (Figure 2.4.2 and Table 2.4.2) was extremely weak, thus precluding transport north into the upper Sacramento Valley. Skies were clear throughout the test period and, with the exception of the Sacramento area, visibilities were excellent. Afternoon visibilities in the Sacramento area were reduced to 7 miles. Surface tempertures were near or slightly above normal with highs on the 9th ranging from 94°F at Sacramento to 100°F at Red Bluff and Redding.

Mixing Heights

Figures 4.1.2 and 4.1.3 show the temperatures aloft at Sacramento during the test. Based on the temperature profiles and maximum surface temperature reported, the mixing layer from thermal buoyancy could be expected to reach a depth of 500 m and 700 m on the 9th and 10th, respectively. Mixing heights were determined from the aircraft soundings by noting the vertical distribution of pollutants or the extent of low-level turbulence. The aircraft sampled at several locations in the Delta and Sacramento regions. Table 4.1.1 gives the mixing heights for all aircraft soundings taken on 9 August.

Transport Winds

The vertical and temporal characteristics of the winds at the tracer release site are described by the pibal data from Vallejo shown in Figure 4.1.4. The presence of low stratus overcast during the release enabled tracking only to cloud base. During that period, winds below cloud base were from the southwest to west at 4-5 m/s. With the exception of the 1300 PDT observation, winds continued from the southwest at all levels to 1900 m

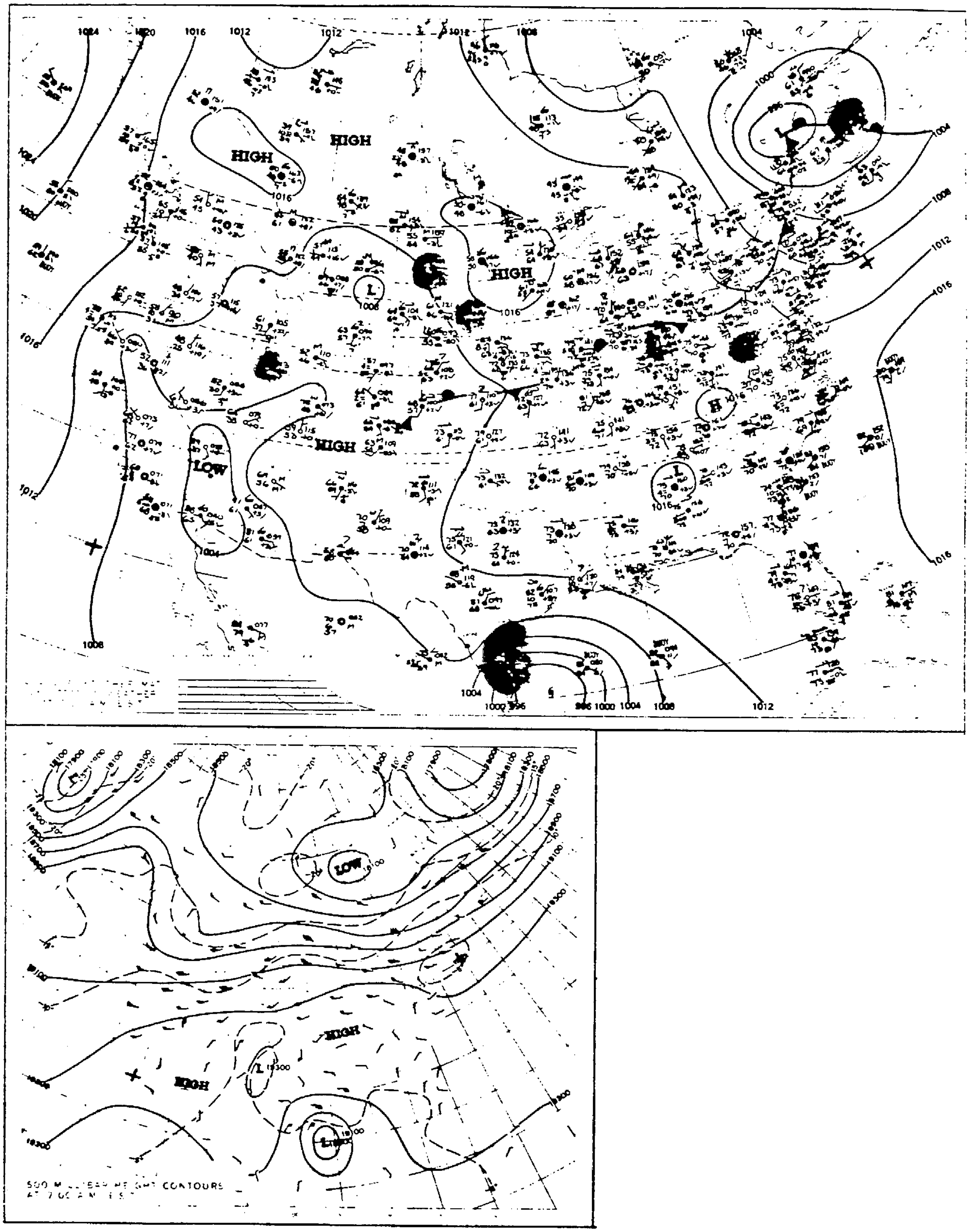


Figure 4.1.1 Surface and 500 mb Weather Charts - 9 August 1980 (0500 PDT)

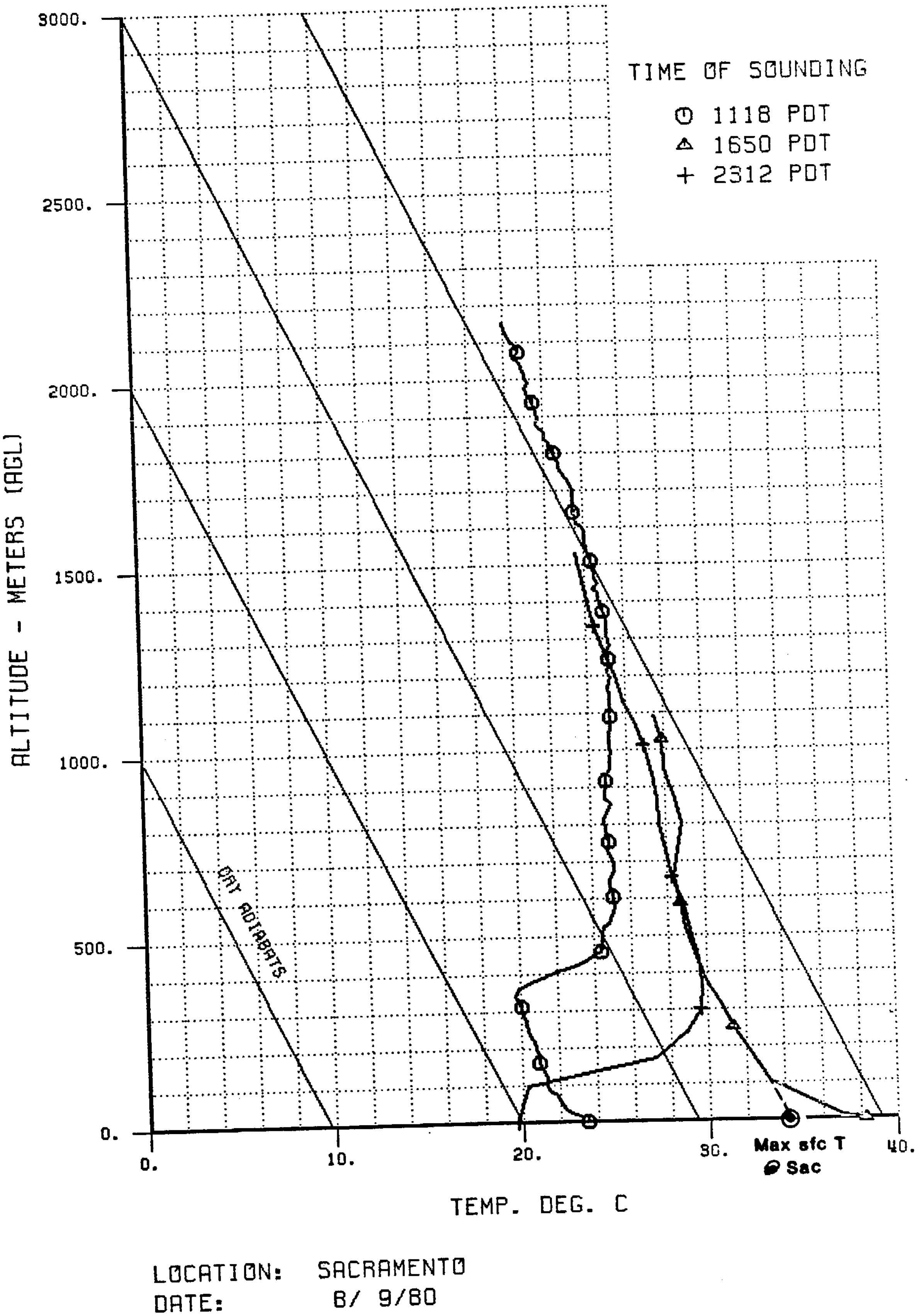


Figure 4.1.2 Temperature Profiles. Dashed line is potential temperature based on maximum surface temperature.

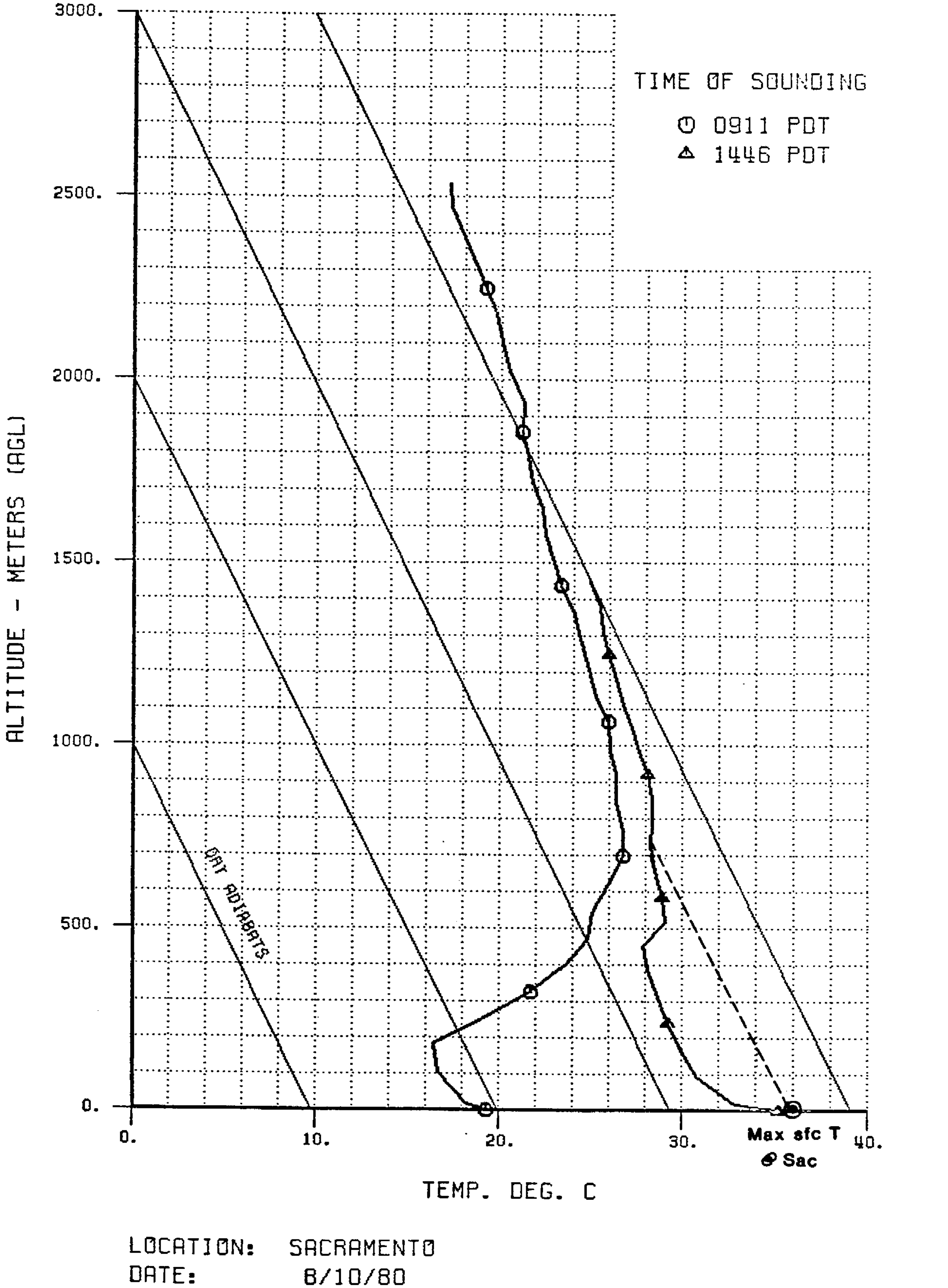


Figure 4.1.3 Temperature Profiles. Dashed line is potential temperature based on maximum surface temperature.

Table 4.1.1

Aircraft Mixing Heights
9 August 1980

Time (PDT)	Location*	Mixing Height (m-agl)
1112	Sac Exec Airport (Pt. 1)	300
1158	Antioch Airport (Pt. 2)	450
1231	Travis Aero Club (Pt. 3)	350
1344	13 SW Sac Exec Airport (Pt. 6)	675
1415	12 SE Sac Exec Airport (Pt. 7)	450

*Distance in miles (see Figure 4.1.6)

Table 4.1.2

Surface Winds at Sacramento Metropolitan Airport
9 August 1980

Time (PDT)	Winds (m/s)
0600	130/2.5
0700	110/2.0
0800	070/2.0
0900	340/2.0
1000	140/2.5
1100	050/1.5
1200	360/2.0
1300	090/3.0
1400	030/2.0
1500	030/2.0
1600	070/2.5
1700	040/4.1

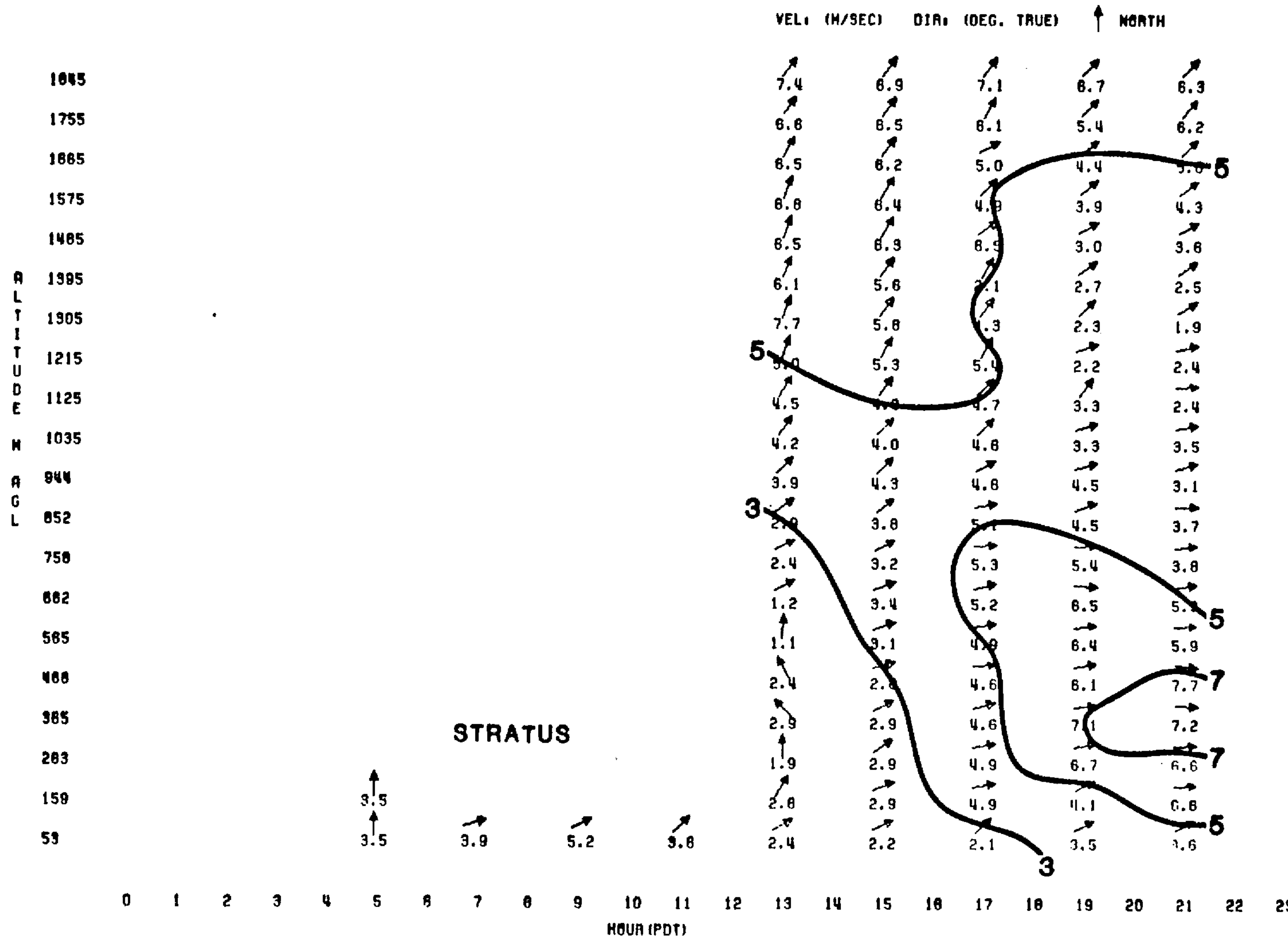


Figure 4.1.4 Vertical Time Section of Winds Aloft at Vallejo Overlook on 9 August 1980. Wind Speed in m/s.

throughout the afternoon. Velocities in the mixing layer ranged from 2-5 m/s. At 1300 PDT, a layer of southeasterly flow was observed between 300-500 m-agl.

The flat north-south pressure gradient in the Valley caused little transport to the northern half of the Valley. The light and variable nature of the winds is clearly illustrated in the surface winds from Sacramento Metropolitan Airport tabulated in Table 4.1.2. An uncharacteristic northerly component to the wind persisted throughout the afternoon.

The time-height cross section of the pibal winds at Sacramento (Figure 4.1.5) generally shows a light wind field in response to the weak pressure gradient within the Valley. A uniform southwesterly flow developed within the mixing layer by 1700 PDT with speeds of 3-5 m/s. Prior to then, the flow was light and disorganized with westerly winds first appearing at low levels by 1300 PDT. No nocturnal jet development was observed during the night of 13-14 August at Sacramento.

4.1.2 Air Quality

Aircraft Sampling

This test was designed to study the flux from the Bay area through the Carquinez Straits and to determine the portion of the streamfield which diverges northward into the Sacramento Valley. To that end, the MRI sampling airplane flew from 1100-1500 PDT on the 9th taking measurements along 1) a north-south cross section perpendicular to the prevailing low level flow through the straits and 2) an east-west cross section from Vacaville to Ione across the southern end of the Sacramento Valley. The flight route is depicted on Figure 4.1.6. Table 4.1.3 summarizes the pollutant concentrations measured during each segment of sampling.

Isopleths of ozone concentrations measured by the airplane along the two cross sections are shown in Figures 4.1.7 and 4.1.8. Figures 4.1.9 to 4.1.11 give plots of all the parameters measured during the spiral over Point 3, located along the Carquinez Straits transect approximately 10 km south of Vacaville. Surface mixing was determined from turbulence and pollutant profiles to extend to 300-350 m-msl across the straits and inversion tops were measured at 500 and 800 m-msl. Maximum NO_x and b_{scat} were measured within the

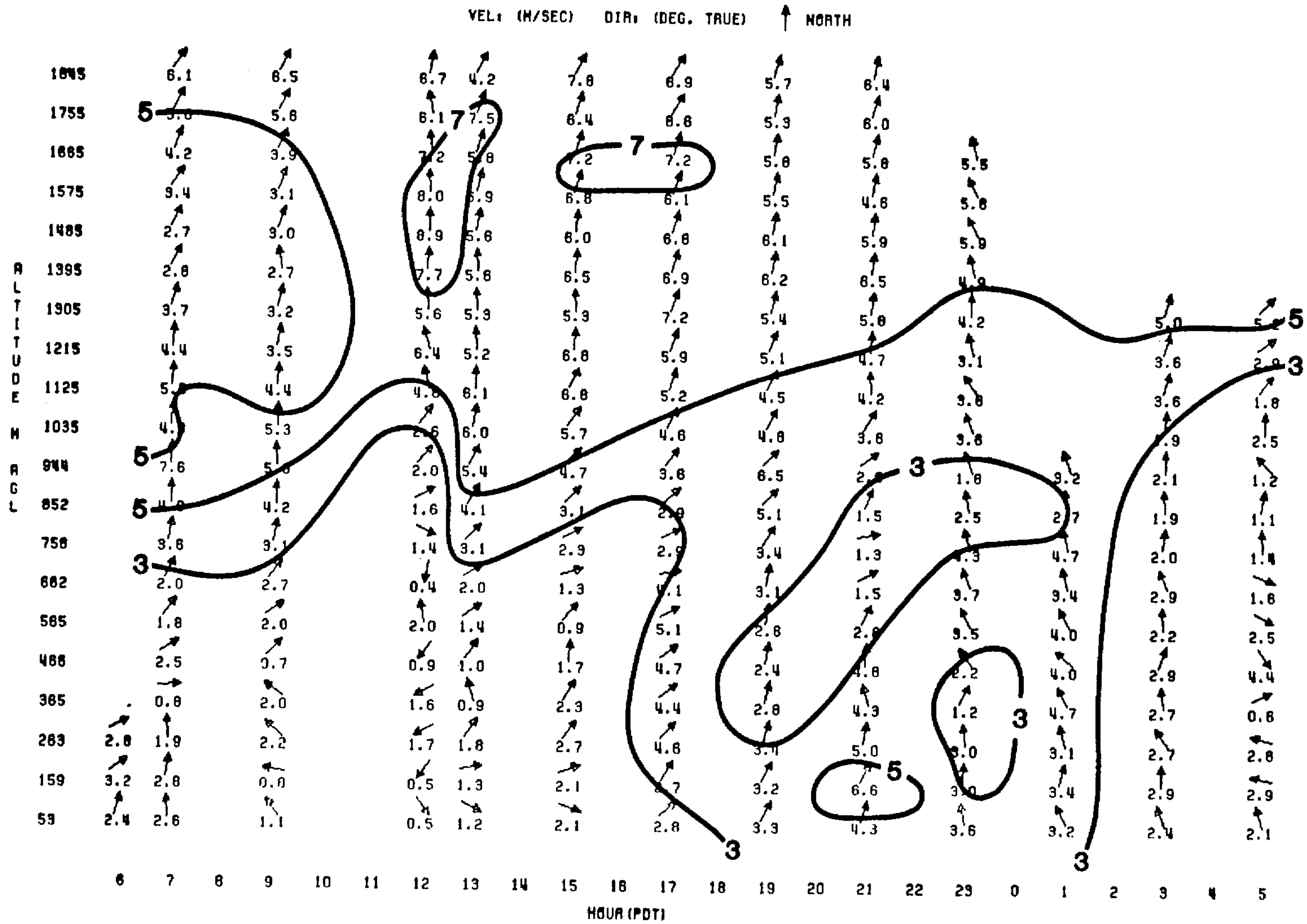


Figure 4.1.5 Vertical Time Section of Winds Aloft at Sacramento (Downtown) on 9 August 1980. Wind Speed in m/s.

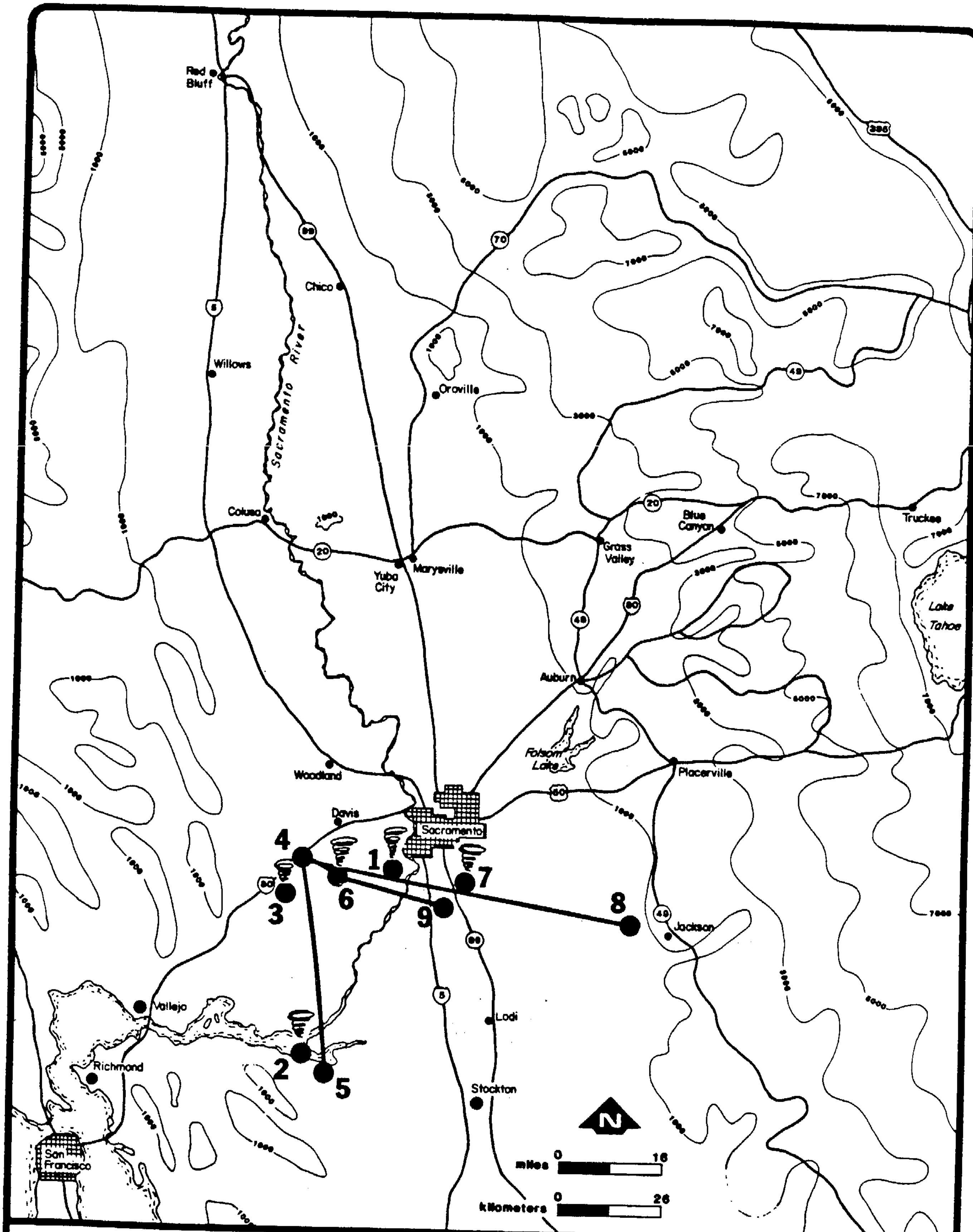


Figure 4.1.6

Sacramento Valley Oxidant Study
MRI 206 Sampling Flight Map
9 August 1980

TEST 1

Tape #147

Table 4.1.3

AIR QUALITY MEASUREMENTS CARB SACRAMENTO VALLEY PROJECT
AUGUST 9, 1980 SAMPLING

Start Time (PDT)	Location (Point)	Altitude (m-msl)	O_3 Mean (ppb)	O_3 Max (ppb)	b_{scat} Mean ($\times 10^{-6} m^{-1}$)	b_{scat} Max ($\times 10^{-6} m^{-1}$)	NO_x Mean (ppb)	NO_x Max (ppb)	NO Mean (ppb)	NO Max (ppb)	SO_2 Mean (ppb)	SO_2 Max (ppb)
1112	1	6-2134	67	89	46	249	7	31	4	15	2	10
-	-	-	-	-	-	-	-	-	-	-	-	-
1158	2	61-1920	67	87	43	131	9	32	4	11	4	20
1231	3	1981-27	67	86	56	176	8	22	3	9	2	6
1248	4-5	305	73	84	113	156	17	115	6	60	6	19
1312	5-4	610	76	91	48	106	7	17	2	7	3	8
1344	6	152-1981	69	90	43	145	7	19	2	9	0	7
1415	7	1981-18	73	111	55	140	5	15	3	11	2	8
1437	8-4	671	83	118	52	149	5	24	2	10	2	8
1506	4-9	366	92	106	98	147	9	28	3	11	4	10

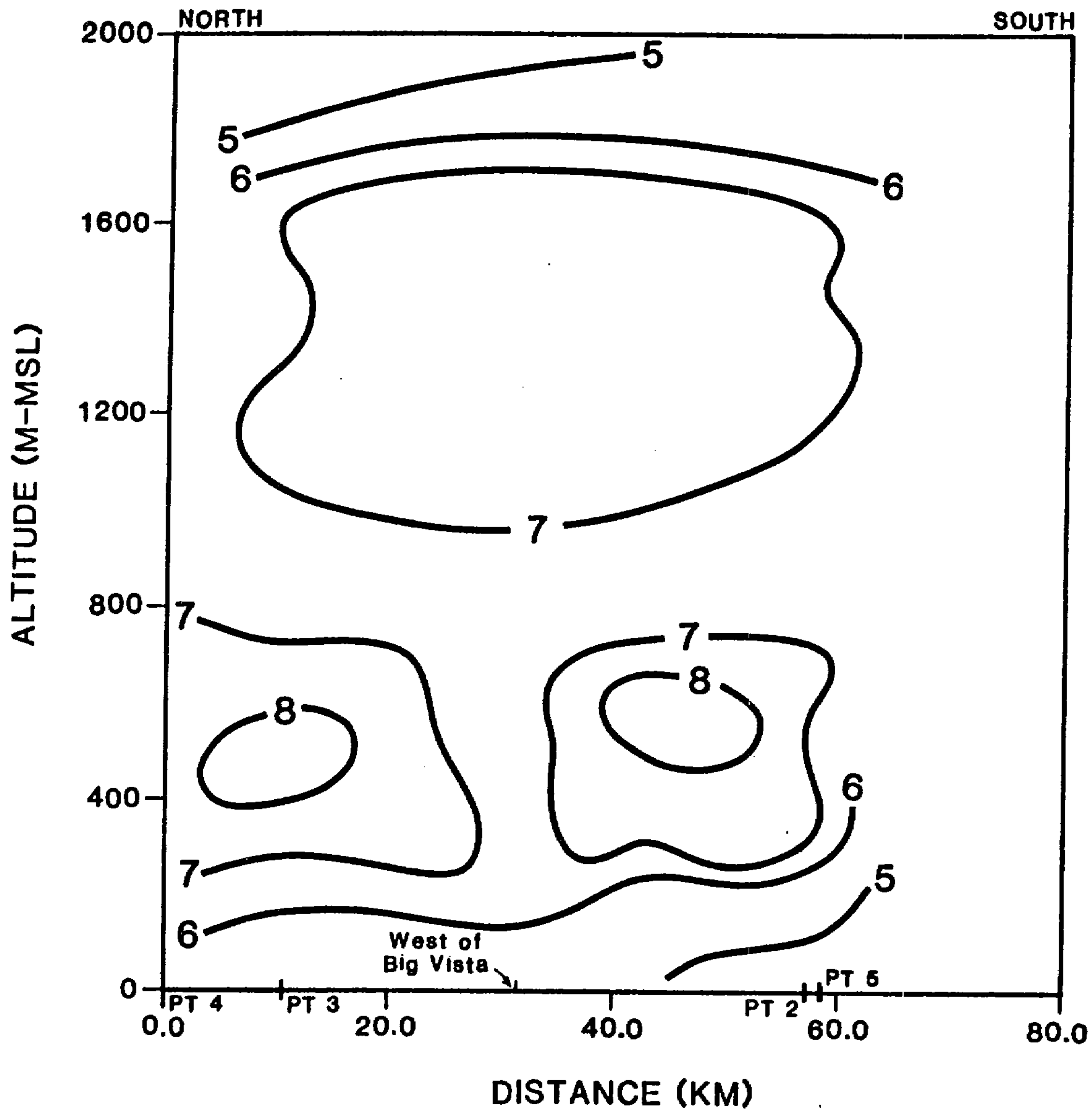


Figure 4.1.7 North-South Cross Vertical Section of Ozone Concentration (pphm) on 9 August 1980. 1158-1329 PDT. Isopleths are labeled in units of pphm.

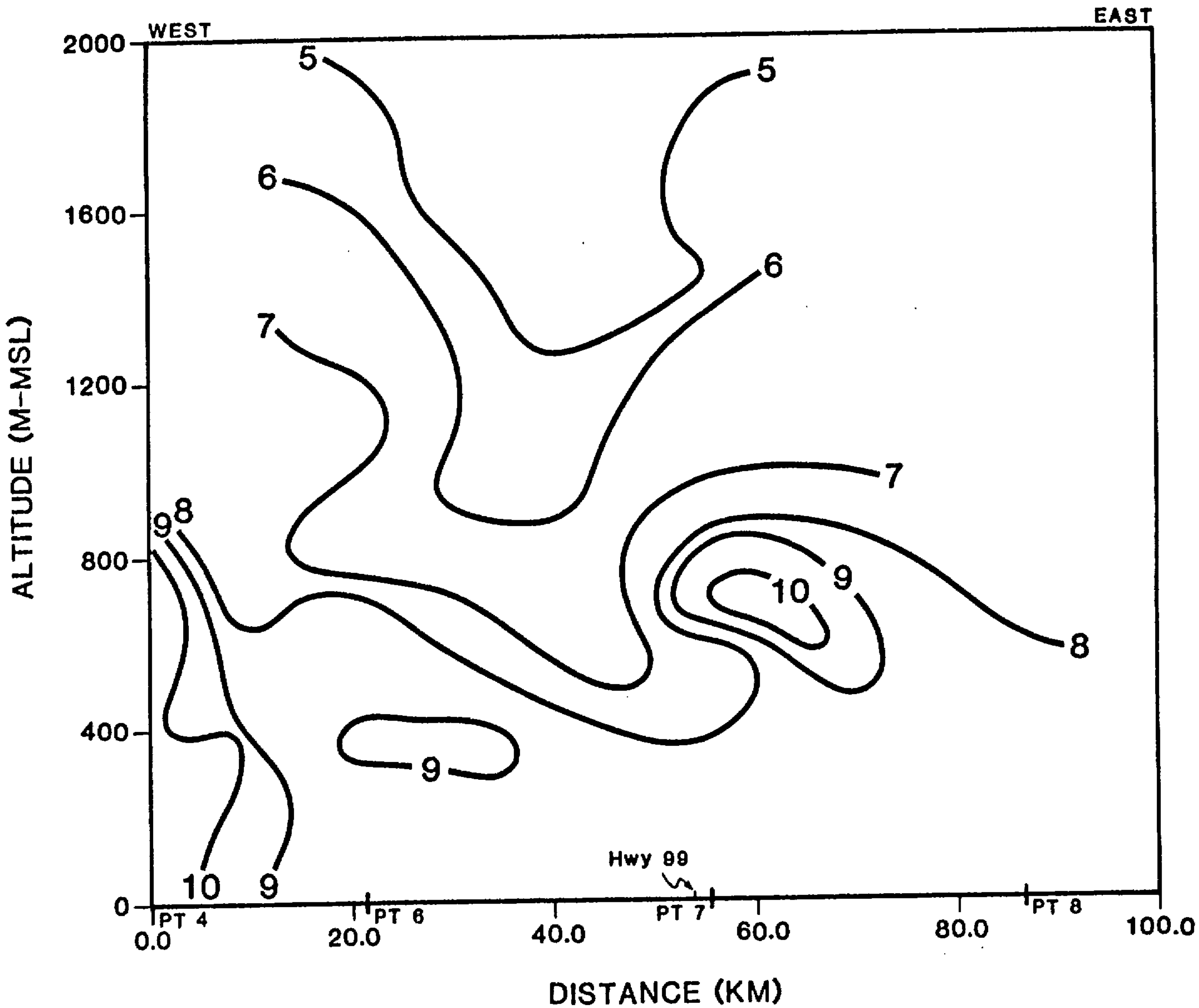


Figure 4.1.8 West-East Vertical Cross Section of Ozone Concentrations on 9 August 1980. 1344-1520 PDT. Isopleths are labeled in units of pphm.

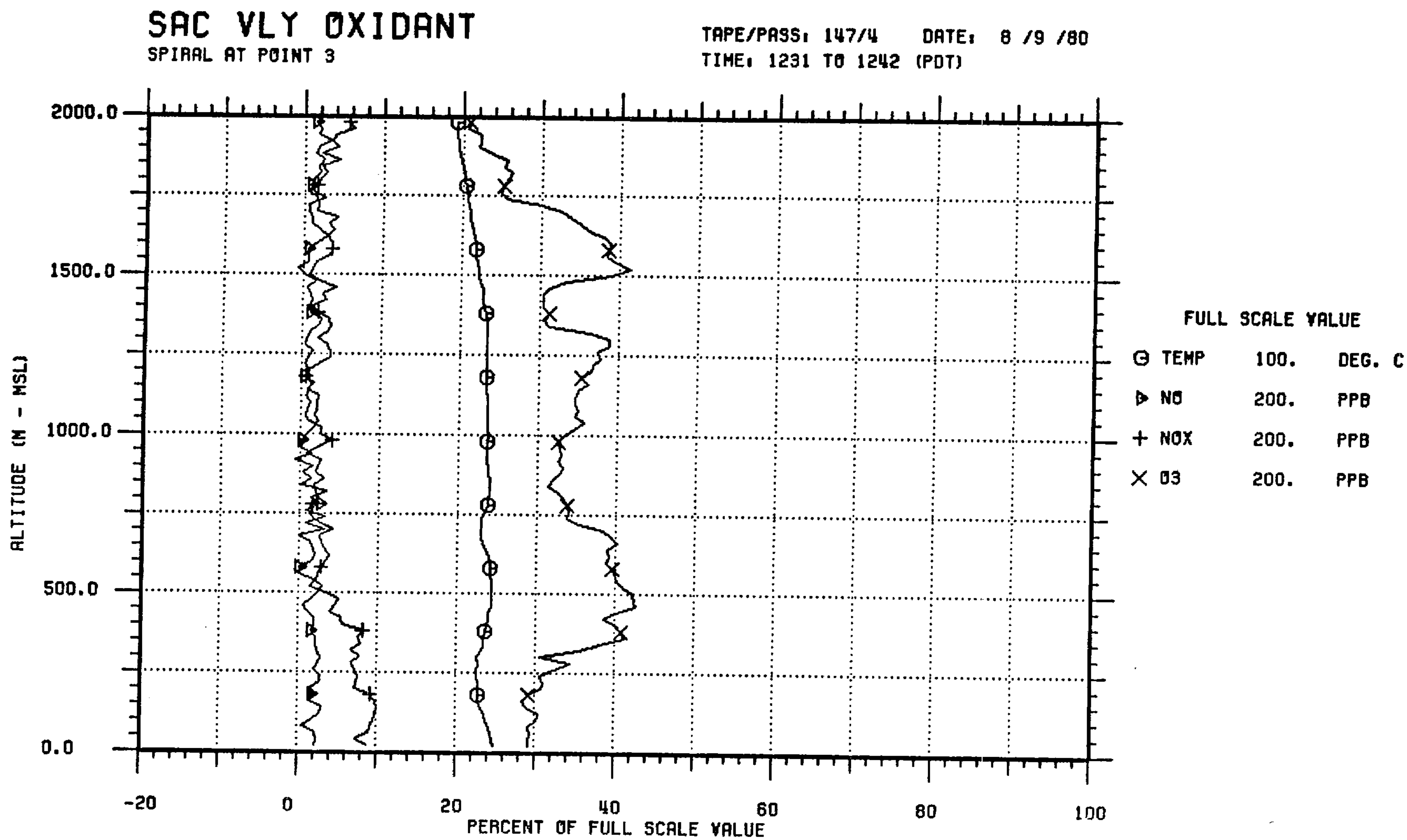


Figure 4.1.9 Aircraft Sounding Over Travis. 9 August 1980. Showing Temperature, NO, NO_x, O_3.

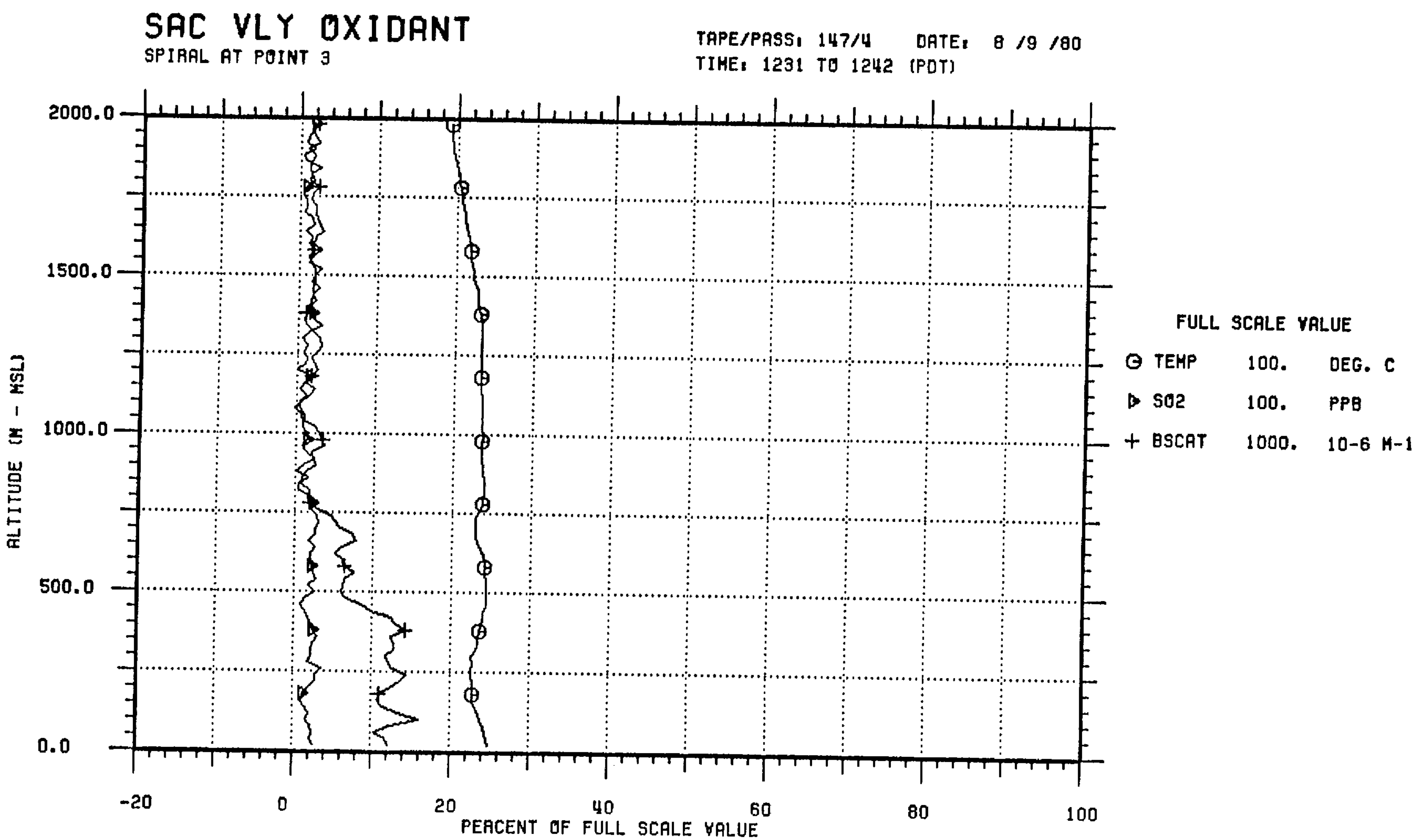


Figure 4.1.10 Aircraft Sounding Over Travis. 9 August 1980. Showing Temperature, SO_2, b_{scat}.

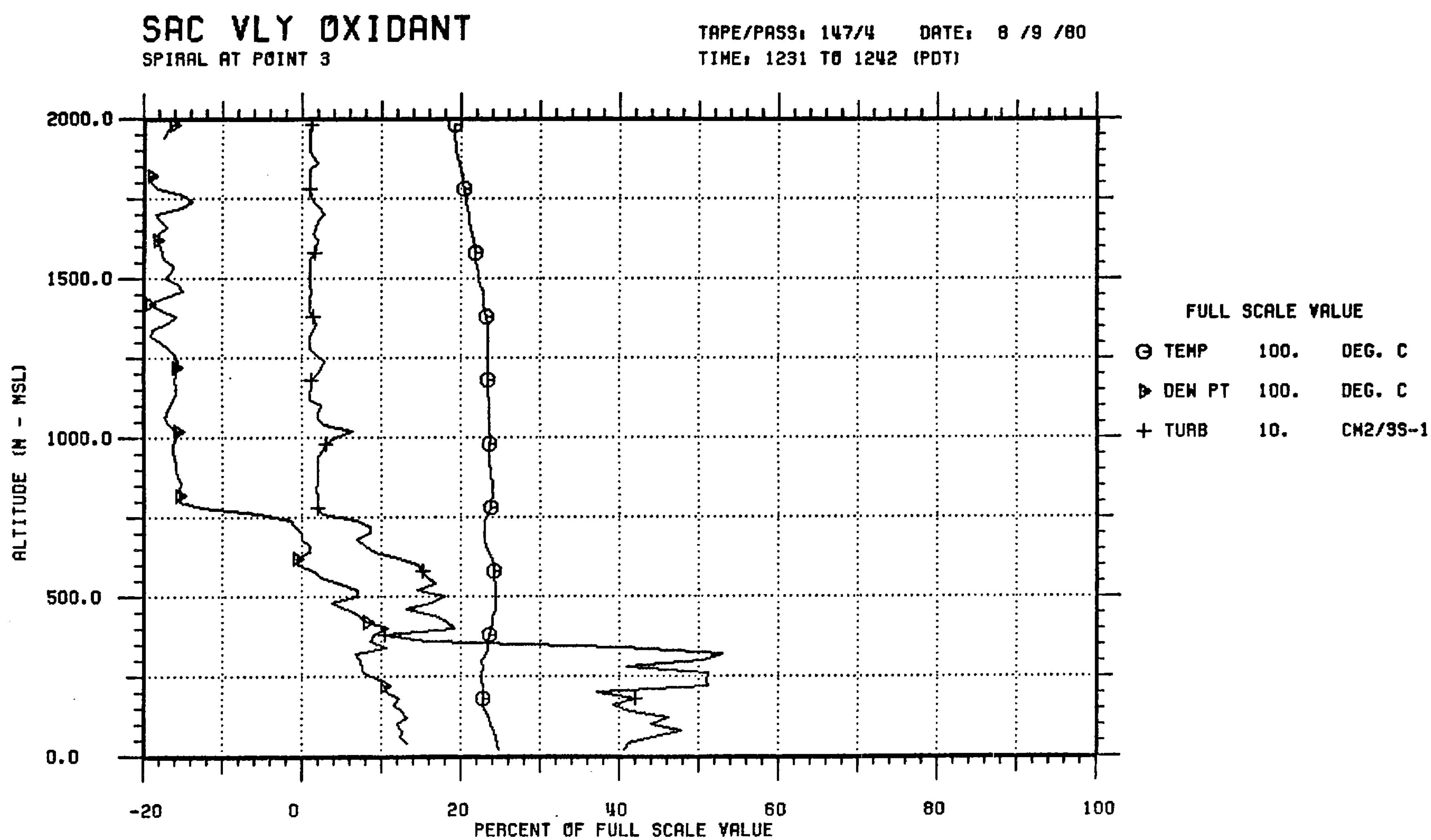


Figure 4.1.11 Aircraft Sounding Over Travis. 9 August 1980. Showing Temperature, Dew Point, Turbulence.

surface mixing layer. The vertical temperature structure shows the atmosphere to be extremely warm and stable below 1500 m. Temperature did not vary more than 3°C within that layer. The region between the two inversions is revealed on the Carquinez Straits cross section (Figure 4.1.7) as an ozone maximum. Although maxima are depicted at both the north and south ends of the transect, the horizontal gradients were nevertheless generally weak. Tracer material was detected along a 300 m-msl traverse in a plume roughly 27 km wide and beginning about 8 km from the north end point. As would be expected, no tracer material was detected along the traverse above the mixing layer (610 m). Unfortunately, winds aloft along the cross section were not measured. However, the 1300 PDT pibal data from the release location, roughly 25 km west, shows a southwest flow from the surface to 400 m, a layer of southeast flow between 500-800 m, and a return to southwest flow above 800 m. Assuming consistency of the wind field in the straits, the lower ozone-rich layer on Figure 4.1.7 is associated with the southeast flow of air exiting the Central Valley. Another ozone maximum is observed on the Carquinez Straits cross section between 1000 and 1600 m within a southwest flow with concentrations in excess of 8 pphm.

The east-west cross section shown in Figure 4.1.8 presents another unanticipated ozone distribution. Referring to Figure 4.1.6, it is seen that Point 4, near Vacaville, is a common end point to both cross sections. Ozone concentrations on the latter cross section now exceed 10 pphm in the lower 600 m in that area whereas approximately 2 hours earlier concentrations were 7 pphm. Coincident with higher ozone concentrations was the presence of tracer material which showed that air with elevated ozone concentrations had been transported from the San Francisco Bay area into the Sacramento Valley. An ozone maximum was also measured aloft between 500-800 m just east of Highway 99. Northerly surface winds in Sacramento and a drop in the dew point imply that the most probable trajectory of this air was over Sacramento. There is no evidence of a connection between this ozone-rich air and the ozone maxima encountered at similar altitudes on the north-south transect. The nearest wind measurements were at Sacramento which showed southwesterly flow at that height.

Regional Surface Oxidant Levels

Hourly averaged surface ozone concentrations for selected locations within the study area are shown in Figure 4.1.12. Despite warm temperatures and poor ventilation, concentrations were only moderate. Exceedances of the State standard (10 pphm) were experienced east of Sacramento at Citrus Heights, Auburn, and Placerville. Sacramento-Creekside (not shown) also exceeded the standard. Maximum concentrations (12 pphm) were measured at Placerville. Timing of oxidant peaks were not appreciably different from monthly diurnal averages.

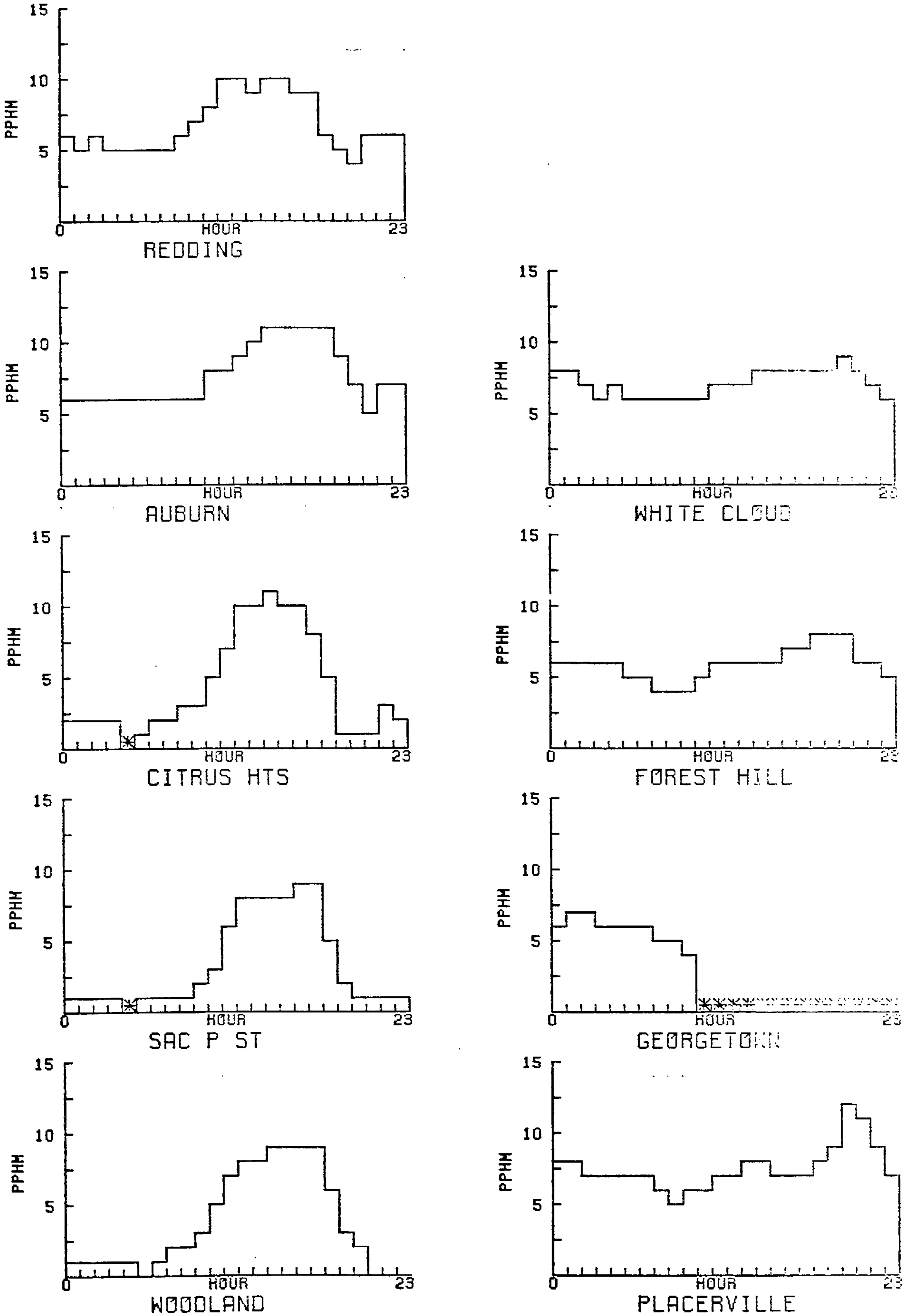


Figure 4.1.12 Hourly Averaged Oxidant Concentrations at Selected Locations. **9 August** 1980. (* indicates missing data).

4.1.3 Tracer Results

SF_6 released at the Vallejo site (in American Canyon above Vallejo) was detected by about 0900 PDT by an automobile traverse along I-680. Figure 4.1.13 shows the tracer concentration measured on selected mobile traverses downwind of the release. The peak concentration was detected about 4 miles south of the intersection of I-680 and I-80. The trajectory of the SF_6 plume thus appeared to be toward Sacramento. Another traverse completed about 1100 PDT indicated that the center of the plume remained in about the same position as it crossed I-680. An automobile traverse found SF_6 levels of about 50 PPT in the vicinity of Nuttree, near Vacaville, and about the same level near the intersection of I-80 and HWY 113. The bulk of the tracer was found to be directly east of Travis AFB, however, by a traverse along HWY 113. By 1630 about 50 PPT of SF_6 was detected along the entire distance of I-5 between Lodi and Stockton.

An airplane traverse between Nuttree and Brentwood at about 1300 PDT also showed that the bulk of the SF_6 was transported east of the release site into the center of the California Delta region. About 150-200 PPT was detected in the vicinity of Rio Vista at this time.

Estimated trajectories of the tracer are shown in Figure 4.1.14. Times of observed maximum concentrations are shown at various points along the trajectories. The principal SF_6 path is indicated to have moved eastward and then southward into the San Joaquin Valley. A divergent branch appears to have been carried into the western slopes of the Sierras.

There was evidence of a minor SF_6 plume moving along I-80, presumably resulting from a temporary change in wind direction near the release site. It is suggested that this pulse may have moved northeastward, resulting in the SF_6 concentrations observed later at Auburn and perhaps accounting for some carry-over noted on the next day. Sacramento was relatively unaffected by the tracer plume. A peak SF_6 concentration of 15 PPT was observed at 19 PDT and may have resulted from a minor extension of the main plume as indicated in Figure 4.1.14.

Small amounts of SF_6 were detected on the following day near Chico and in the Sierra foothills to the east and northeast of Lodi. Concentrations to 35 PPT were observed in these areas on the morning of August 10. Small concentrations of SF_6 (14, 10 PPT) were also observed on August 10 at South Tahoe which may indicate a weak transport to the upper slopes of the Sierras.

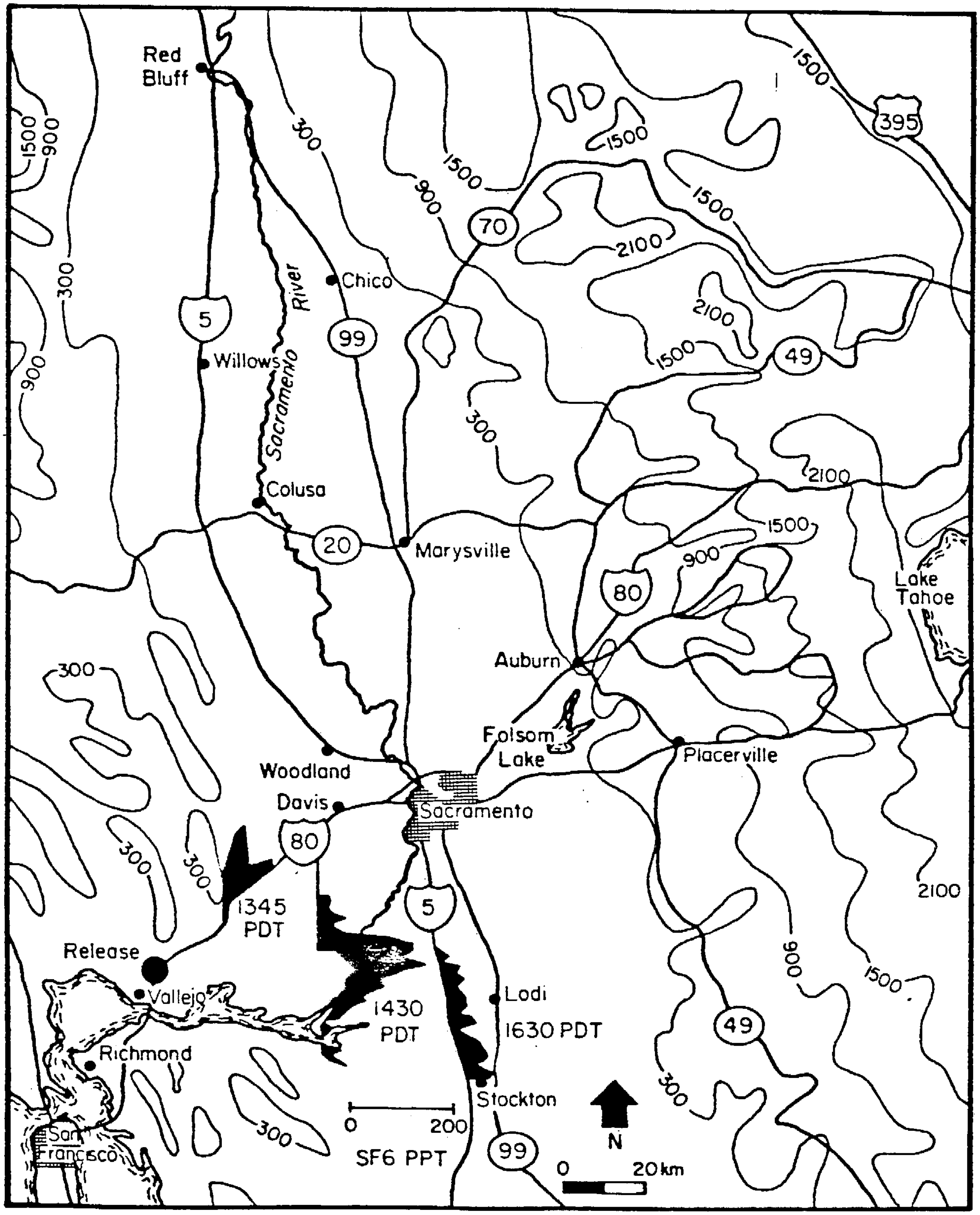


Figure 4.1.13 SF_6 Concentrations from Automobile Traverses Test 1 - August 9, 1980 (height of shaded area proportional to concentration).

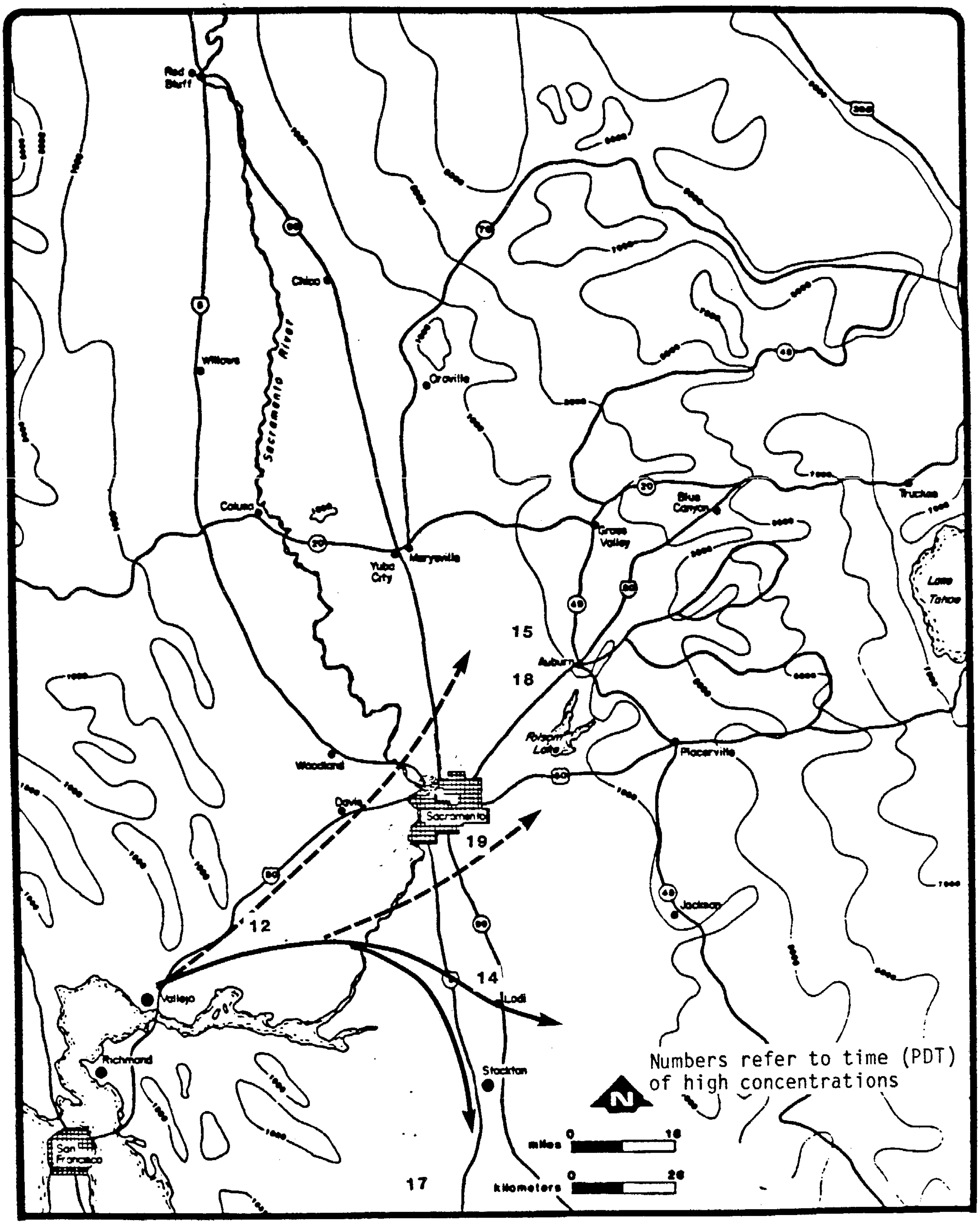


Figure 4.1.14 Tracer Trajectories - Test 1
August 9, 1980 - 0620-1120 PDT

4.2 Test 2 13-14 August 1980, Downtown Sacramento Release (0600-1100 PDT)

4.2.1 Meteorology

General

The synoptic meteorology on August 13-14 was characterized by a major shift in the long wave pattern to a regime which would persist the remainder of August and cause unseasonably cool temperatures in Northern California. From Figure 2.4.3 it is seen that the 850 mb temperature at Oakland dropped from 22.6°C on the morning of the 13th to 18.8°C by the following morning. However, as depicted on the 12Z weather charts in Figure 4.2.1, meteorological conditions remained conducive to testing on the 13th. A thermal trough was established over the interior of California with high pressure offshore and fair weather prevailed. The afternoon onshore pressure gradient (5.1 mb) during this test was greater than on any of the other tests (Table 2.4.2). The north-south pressure gradient (Figure 2.4.2) in the Sacramento Valley was sufficiently strong enough to assure good transport to the north. Skies were generally clear in the Sacramento Valley on the 13th although scattered high clouds were observed in the north late in the period. On the 14th, the passage of a short wave trough through the area caused widespread cloudiness. Maximum surface temperatures experienced on the 13th ranged from 82°F at Sacramento, some 10° below the normal for August, to the mid-nineties in the north.

Mixing Heights

Temperatures aloft at Sacramento on August 13, obtained by scheduled airsonde observations, are shown in Figure 4.2.2. A strong inversion persisted throughout the day, limiting the depth of surface mixing to about 500 m. Aircraft mixing heights were measured at two locations on the morning of the 13th and at three locations during the afternoon. These data are summarized in Table 4.2.1. Mixing heights in the afternoon were uniform in the Valley and in the Sierra foothills.

Transport Winds

The surface winds during the morning and afternoon from Sacramento Executive Airport, about 6 km south of the release site, and from Chico are tabulated in Table 4.2.2. The flow at Sacramento was typically upvalley in

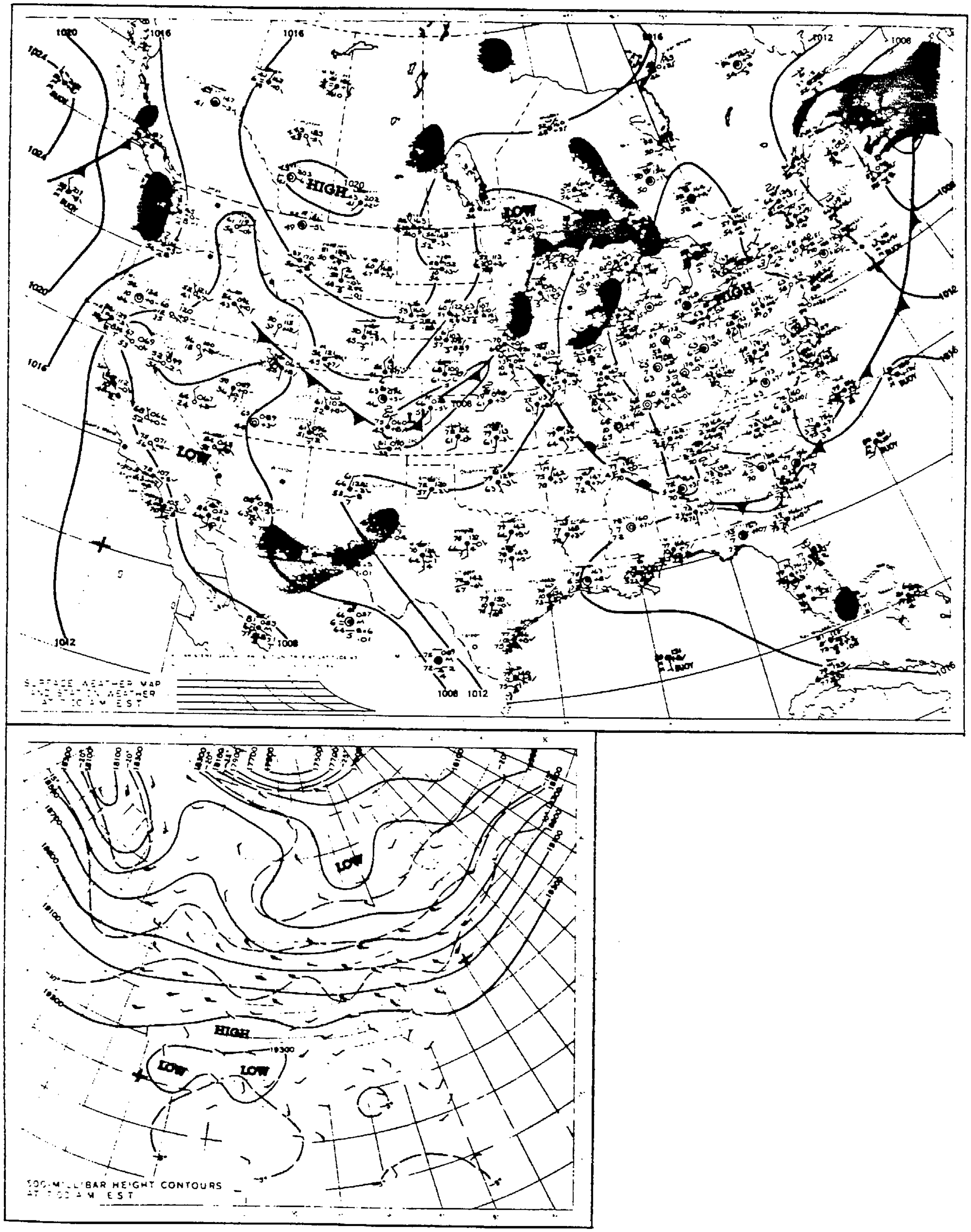


Figure 4.2.1 Surface and 500 mb Weather Charts - 13 August 1980 (0500 PDT)

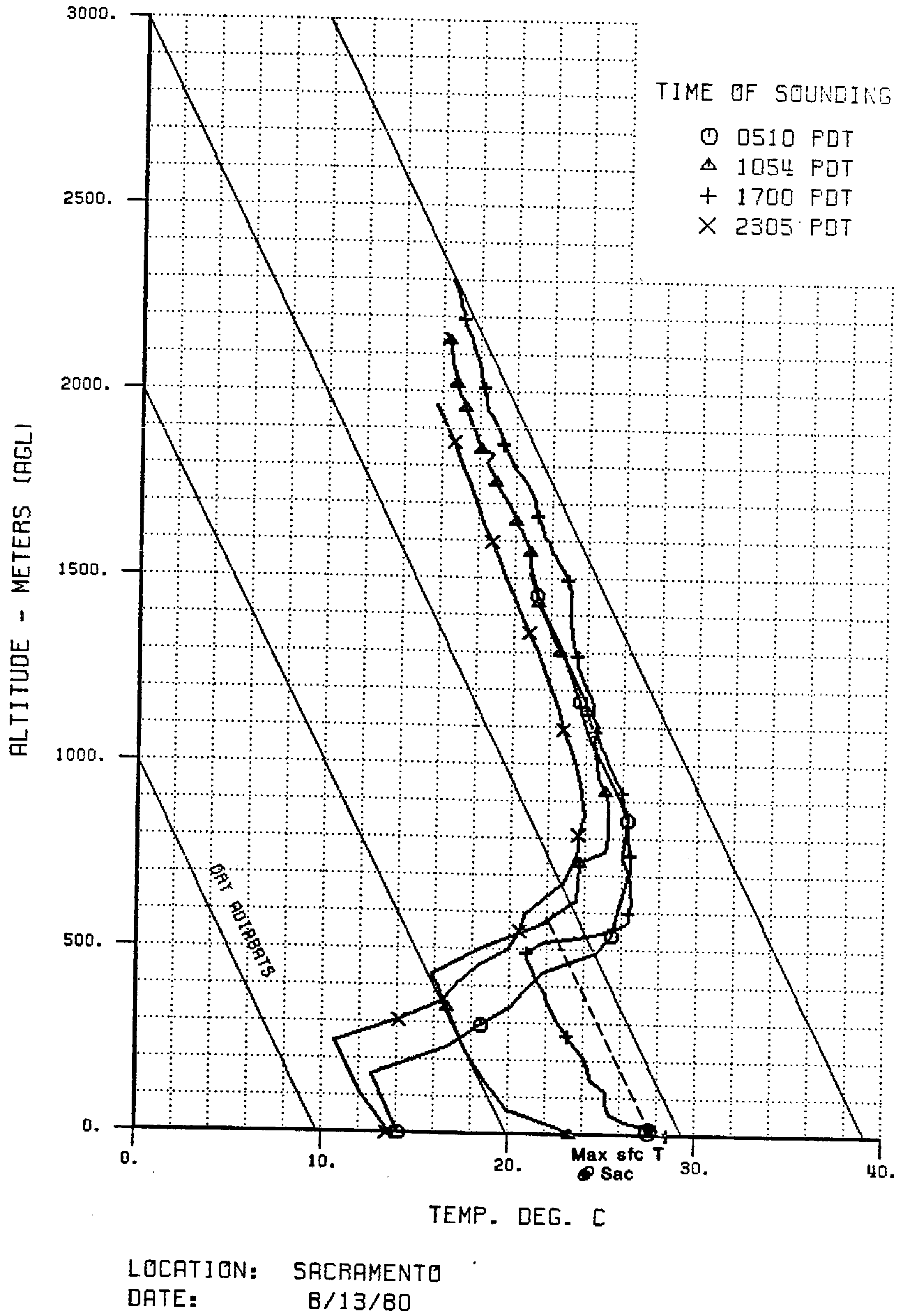


Figure 4.2.2 Temperature Profiles. Dashed line is potential temperature based on maximum surface temperature.

Table 4.2.1

Aircraft Mixing Heights
13 August 1980

Time (PDT)	Location*	Mixing Height (m-agl)
0620	5 SW Sac Exec Airport	200
0656	Rio Linda Airport (8 N Sac Exec)	100
1500	Lincoln Airport (Pt. 5)	510
1655	Big Oak Valley Airport (Pt. 10)	530
1722	Nevada County Airport (Pt. 11)	550

*Distance measured in miles (see Figure 4.2.6)

Table 4.2.2

Surface Winds at Sacramento and Chico
13 August 1980

Time (PDT)	Sacramento Executive Airport Wind (m/s)	Chico Wind (m/s)
0600	210/5.1	-
0700	190/6.1	130/2.5
0800	200/5.1	140/4.1
0900	210/6.1	180/2.5
1000	200/6.6	170/2.5
1100	210/6.6	170/2.5
1200	230/5.6	160/1.5
1300	220/5.1	170/3.1
1400	220/6.1	160/4.1
1500	210/6.1	170/4.6
1600	200/7.1	160/6.1
1700	190/6.1	120/6.1

the morning from the south to southwest at 5-6 m/s becoming more predominately southwest in the afternoon. The winds at Chico were from the south to southeast throughout the period at speeds ranging from 6 m/s in the afternoon to 2.5 m/s in the forenoon hours.

The winds aloft at Sacramento on the 13th and in the early morning of the 14th are depicted in Figure 4.2.3. Winds within the mixing layer, like the surface, were generally south to southwest during the release and in the afternoon with speeds ranging from 4-7 m/s. By 2300 PDT, a southerly nocturnal jet had developed.

Vertical time sections of the winds in the Sierra foothills at Auburn and at the ridgetop site, White Cloud (1323 m elevation), are shown in Figures 4.2.4 and 4.2.5, respectively. At Auburn, easterly or downslope flow was observed until 0900 PDT. After 1100 PDT, south to southwest winds 2-4 m/s were measured in the mixing layer. From 2100-2300 PDT, a moderate (5-7 m/s) southeast flow existed at low levels. Flow generally parallel to the Sierra range persisted the remainder of the night and by 1100 PDT on the following morning upslope flow was again reestablished. At White Cloud, a moderate upslope flow, 4-6 m/s, persisted throughout the afternoon of the 13th. Downslope flow, generally light, occurred near the surface after 1900 PDT. Similar to Auburn, pollution aloft which had been the result of mixing processes that occurred earlier in the day would be transported north roughly parallel to the Sierra crest during the night.

4.2.2 Air Quality

Aircraft Sampling

Sampling missions were flown both in the morning and afternoon of August 13. The morning sampling was discussed in Section 3 of this report. Both the nocturnal inversion and the winds were stronger than typically found at Sacramento, but no significant pollutant accumulation was measured. Ozone concentrations greater than 80 ppb were measured aloft at 1000 and 1500 meters in the area. Afternoon sampling consisted of a series of traverses and spirals downwind to the north and northeast of Sacramento. The sampling included a traverse along the eastern edge of the Sacramento Valley and a traverse from Grass Valley to Auburn. The complete sampling pattern is depicted in Figure 4.2.6. All traverses were flown within the

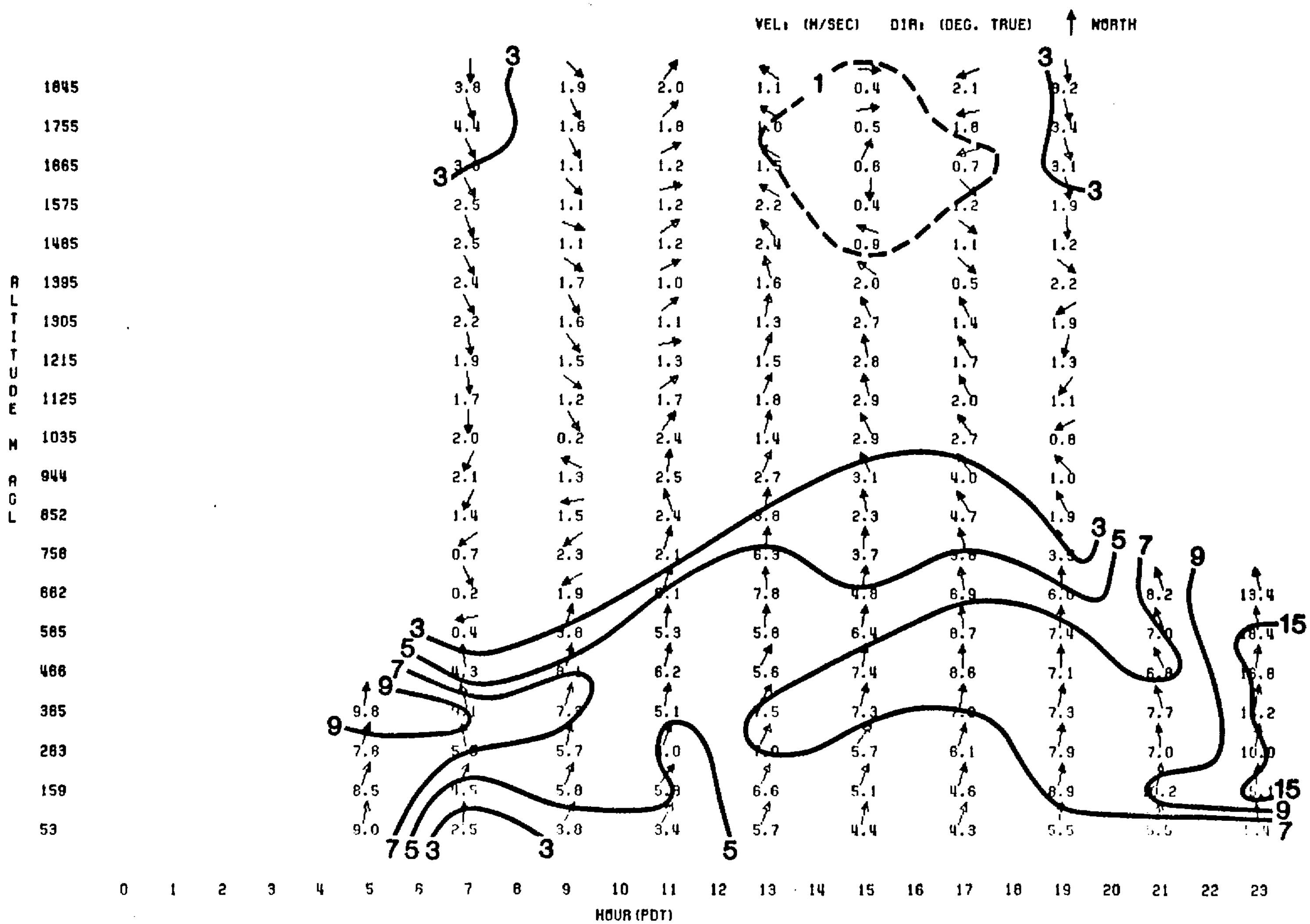


Figure 4.2.3 Vertical Time Section of Winds Aloft at Sacramento (Downtown) on 13 August 1980. Wind Speed in m/s.

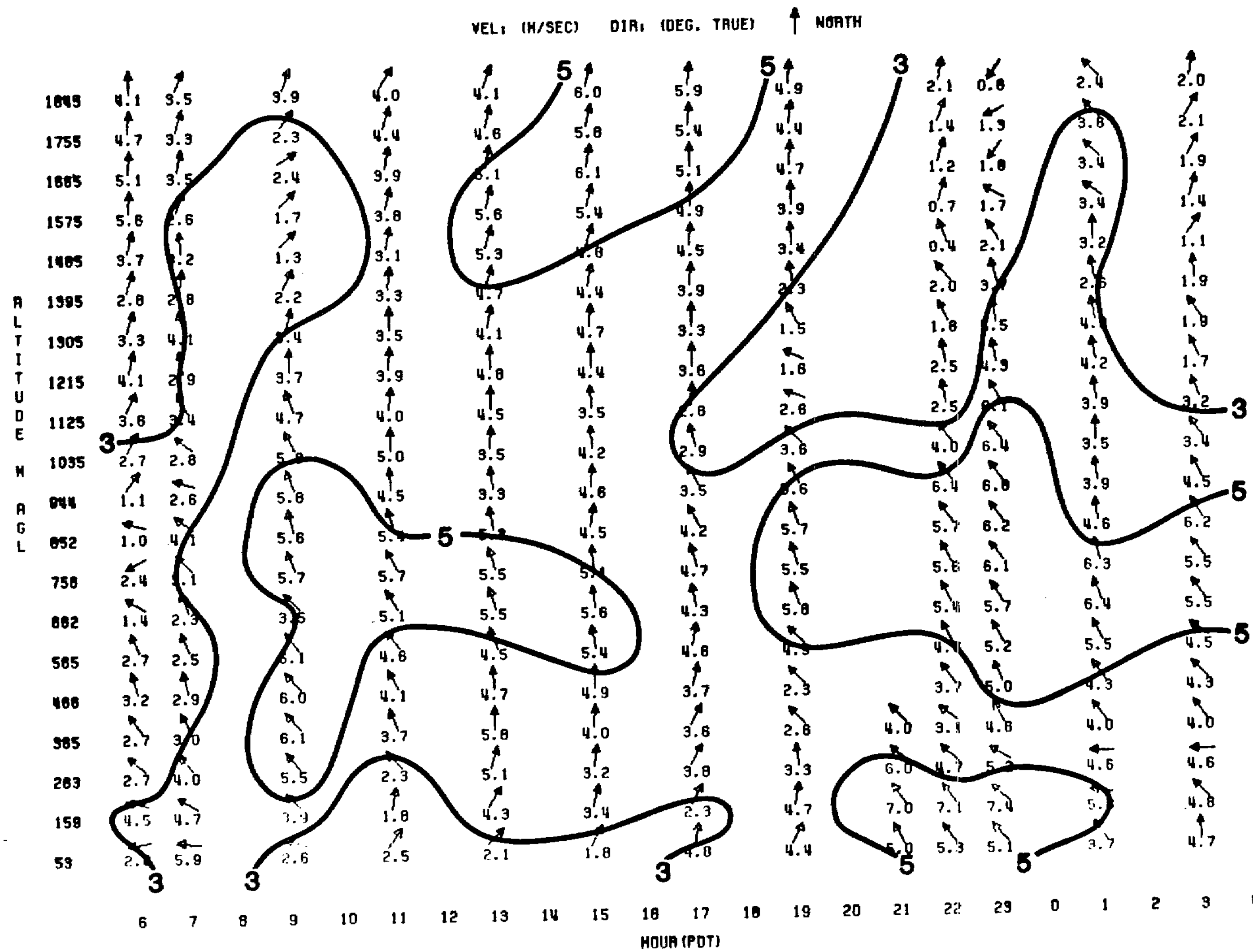


Figure 4.2.4 Vertical Time Section of Winds Aloft at Auburn on 13-14 August 1980. Wind Speed in m/s.

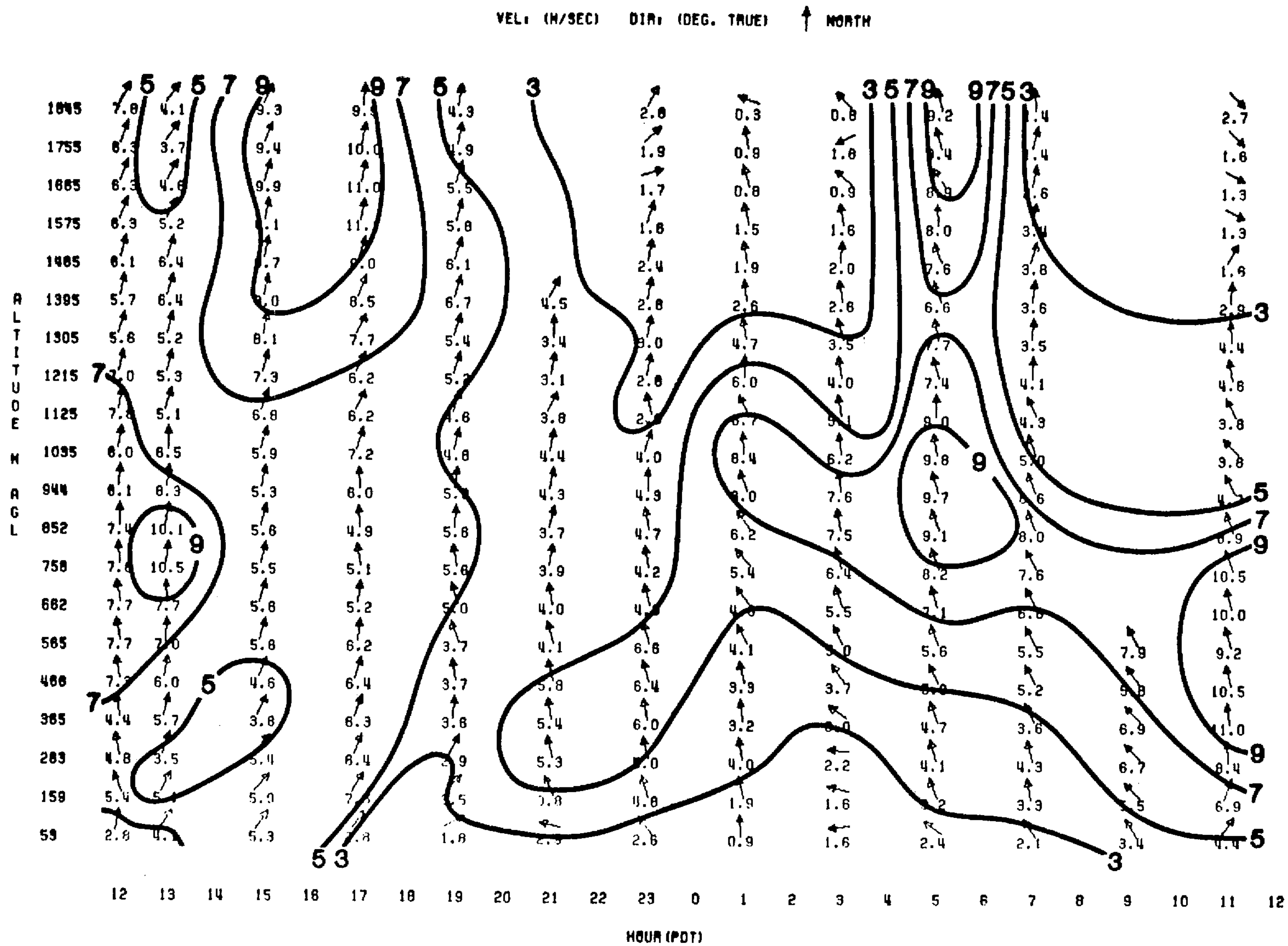


Figure 4.2.5 Vertical Time Section of Winds Aloft at White Cloud on 13-14 August 1980. Wind Speed in m/s.

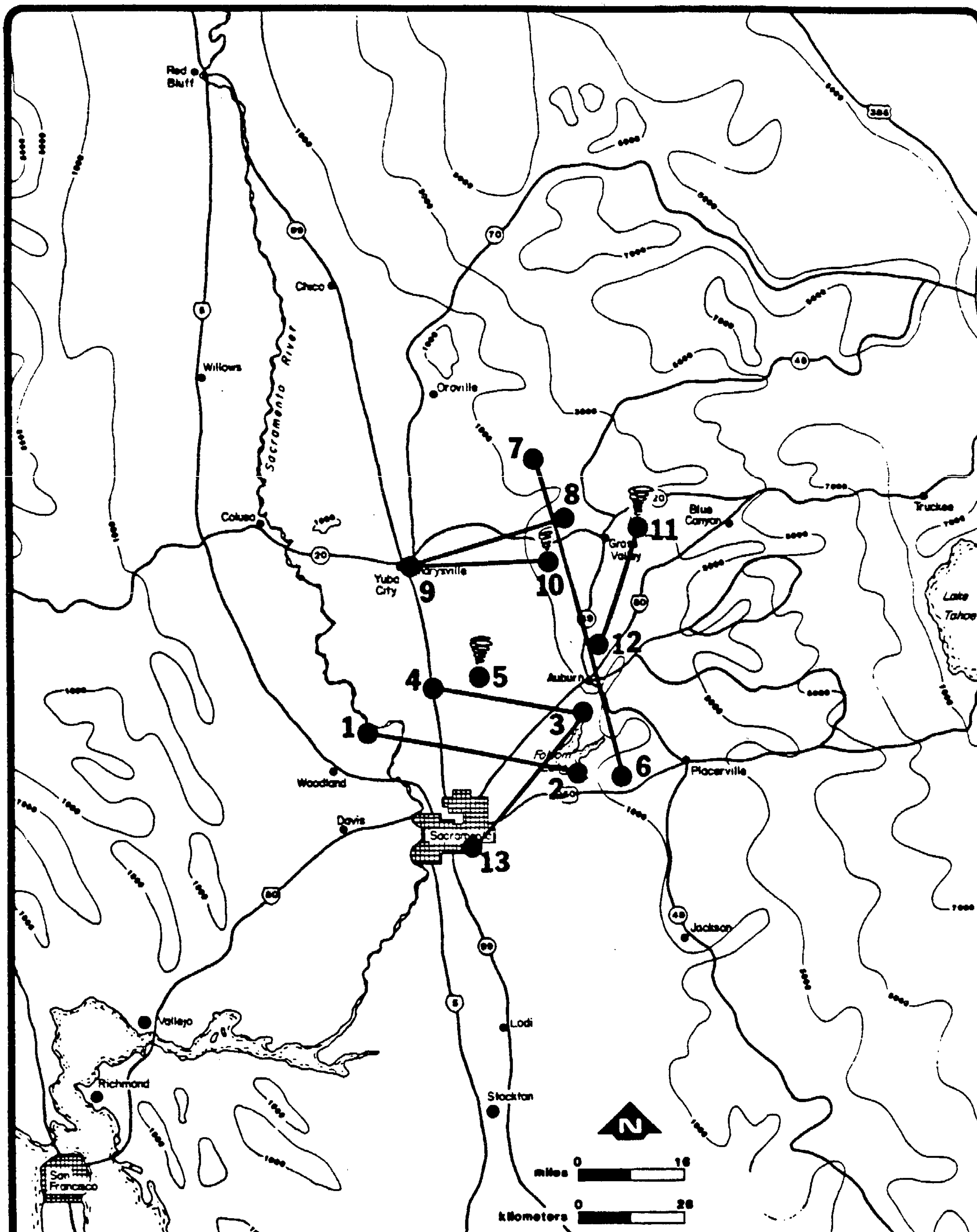


Figure 4.2.6
Sacramento Valley Oxidant Study
MRI 206 Sampling Flight Map

TEST 2 | 13 August 1980 | Tape #149

surface mixing layer. Table 4.2.3 is a summary of the measurements on each segment of the afternoon sampling flight.

Consistent with the transport winds, the major impact of the Sacramento urban plume was measured northeast of the city and was distinguished by the ozone and NO_x distribution shown in Figure 4.2.7. This figure shows the measurements along a 300 m altitude traverse from Highway 99, approximately 35 km north of Sacramento near East Nicholaus, east to the north tip of Folsom Lake (Point 4-3 in Figure 4.2.6). A broad ozone and NO_x plume began near Lincoln (Point 5) and continued east into the foothills. The urban plume is even more in evidence 65 km downwind on the traverse from Marysville east to Big Oak Valley (Point 9-10) shown in Figure 4.2.8. Ozone increased from 8 pphm at Marysville to over 10 pphm just east of Beale AFB. The ozone-temperature vertical profiles on Figure 4.2.9 further define the urban air. Integrated ozone concentrations within the mixing layer were 8.6 pphm at Lincoln Airport (Figure 4.2.9a) and 10.5 pphm at Big Oak Valley Airport (Figure 4.2.9b), reflecting the increase in ozone burden as the smog matured. Although not well mixed, the intrusion of urban air into the foothills is clearly shown in the sounding data over Nevada Co. Airport (Figure 4.2.9c). Maximum ozone concentrations there reached 10 pphm near the surface. The major features of these soundings are shown in Table 4.2.4. Note the consistency in depth of the mixing layer at the three locations. The increased ozone loading in the mixing layer between Lincoln and Big Oak Valley is clearly evident from the data in the table. These calculations are of special significance because, based on the winds discussed in the previous section, the same air mass may have been sampled at both locations. The traverse north (not shown), paralleling the mountains from Cameron Park to near Collins Lake (approximately 30 km northeast of Marysville), measured maximum ozone concentrations north of I-80, increasing to over 11 pphm east of Spenceville. This traverse route is depicted on Figure 4.2.6 as Point 6 to Point 7.

Regional Surface Oxidant Levels

Hourly averaged surface ozone concentrations for selected locations within the study area are shown in Figure 4.2.10. No exceedances of the State standard were reported. The good ventilation experienced in Sacramento is reflected in low concentrations at Sacramento and Citrus Heights, and in the early peak (1600 PDT) recorded at Auburn. Maximum ozone concentations

Table 4.2.3

AIR QUALITY MEASUREMENTS CARB SACRAMENTO VALLEY PROJECT
AUGUST 13, 1980 SAMPLING

Start Time (PDT)	Location (Point)	Altitude (m-msl)	O_3		b_{scat}		NO_x		NO		SO_2	
			Mean (ppb)	Max (ppb)	Mean ($x10^{-6}m^{-1}$)	Max	Mean (ppb)	Max (ppb)	Mean (ppb)	Max (ppb)	Mean (ppb)	Max (ppb)
1416	1-2	610-792	86	92	44	93	4	10	4	8	1	3
1443	3-4	610	76	88	84	149	14	30	5	11	2	5
1500	5	46-1981	75	94	65	176	7	27	4	11	1	3
-	-	-	-	-	-	-	-	-	-	-	-	-
1538	4-3	305	88	96	130	183	20	31	6	11	2	4
1559	6-7	610	95	109	106	170	16	28	4	11	3	5
1633	8-9	457	90	109	83	156	12	22	4	10	0	2
1646	9-10	457	91	111	92	170	11	21	4	10	0	2
1655	10	305-2438	76	109	52	179	9	22	4	11	1	3
1722	11	2438-966	61	99	27	79	6	15	3	0	0	2
1738	11-12	1067	91	109	65	113	12	18	3	7	0	1
1752	3-13	549	83	94	87	140	11	22	4	9	1	5

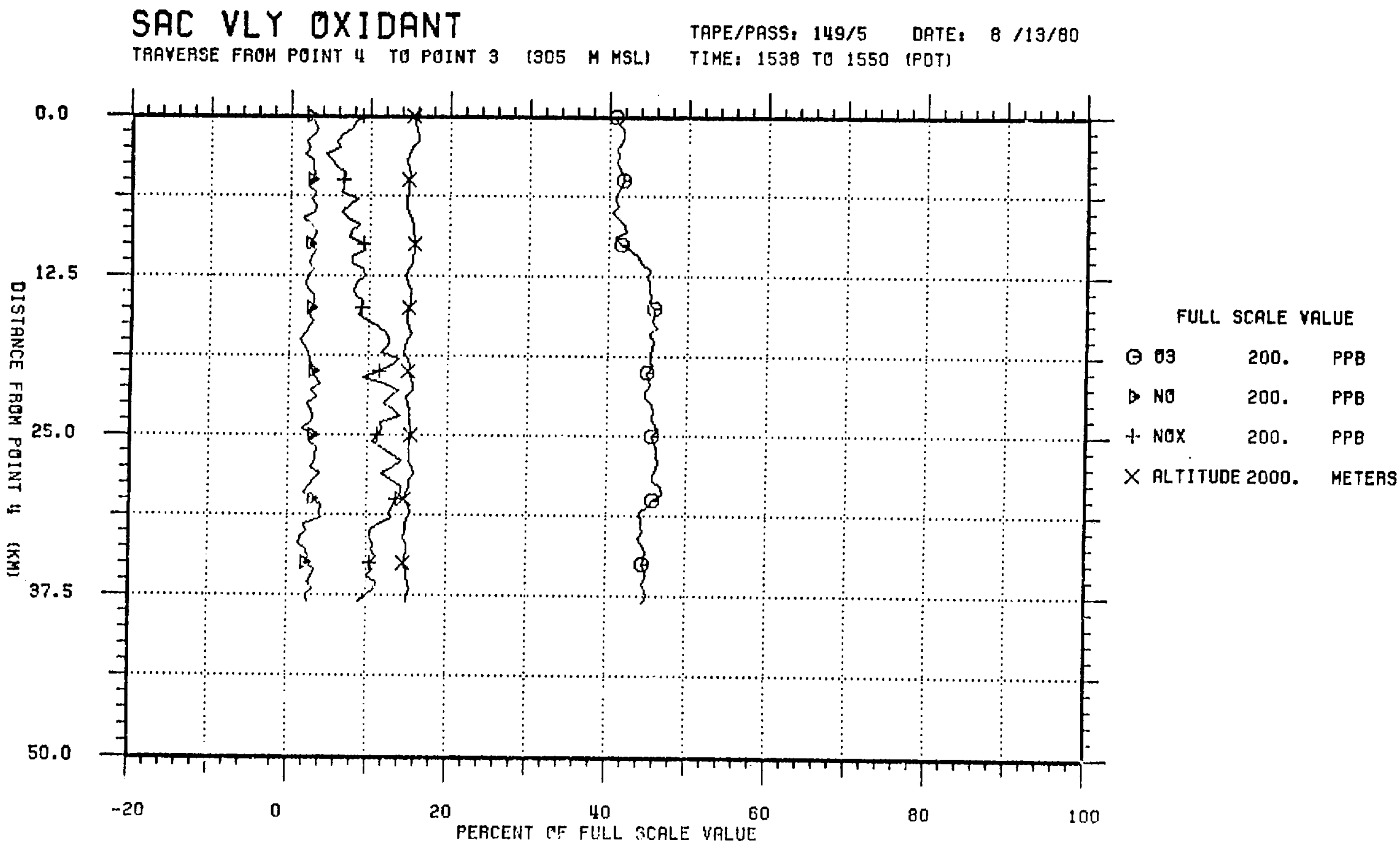


Figure 4.2.7 Airplane Traverse from Near E. Nicolaus to Folsom Lake. 305 m-msl. 13 August 1980. Showing NO, NO_x, O_3.

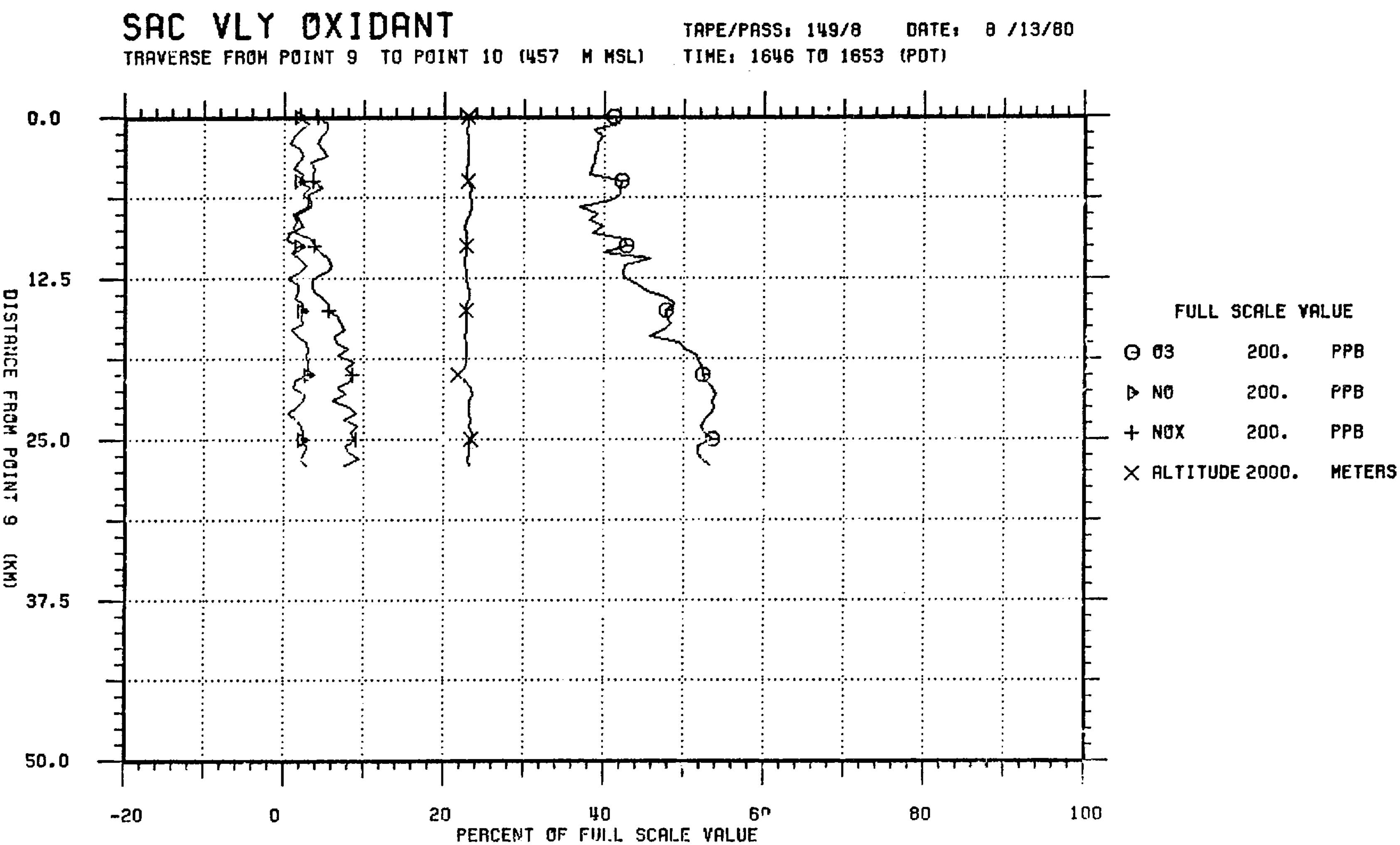


Figure 4.2.8 Airplane Traverse from Marysville to Big Oak Valley. 457 m-msl. 13 August 1980. Showing NO, NO_x, O_3.

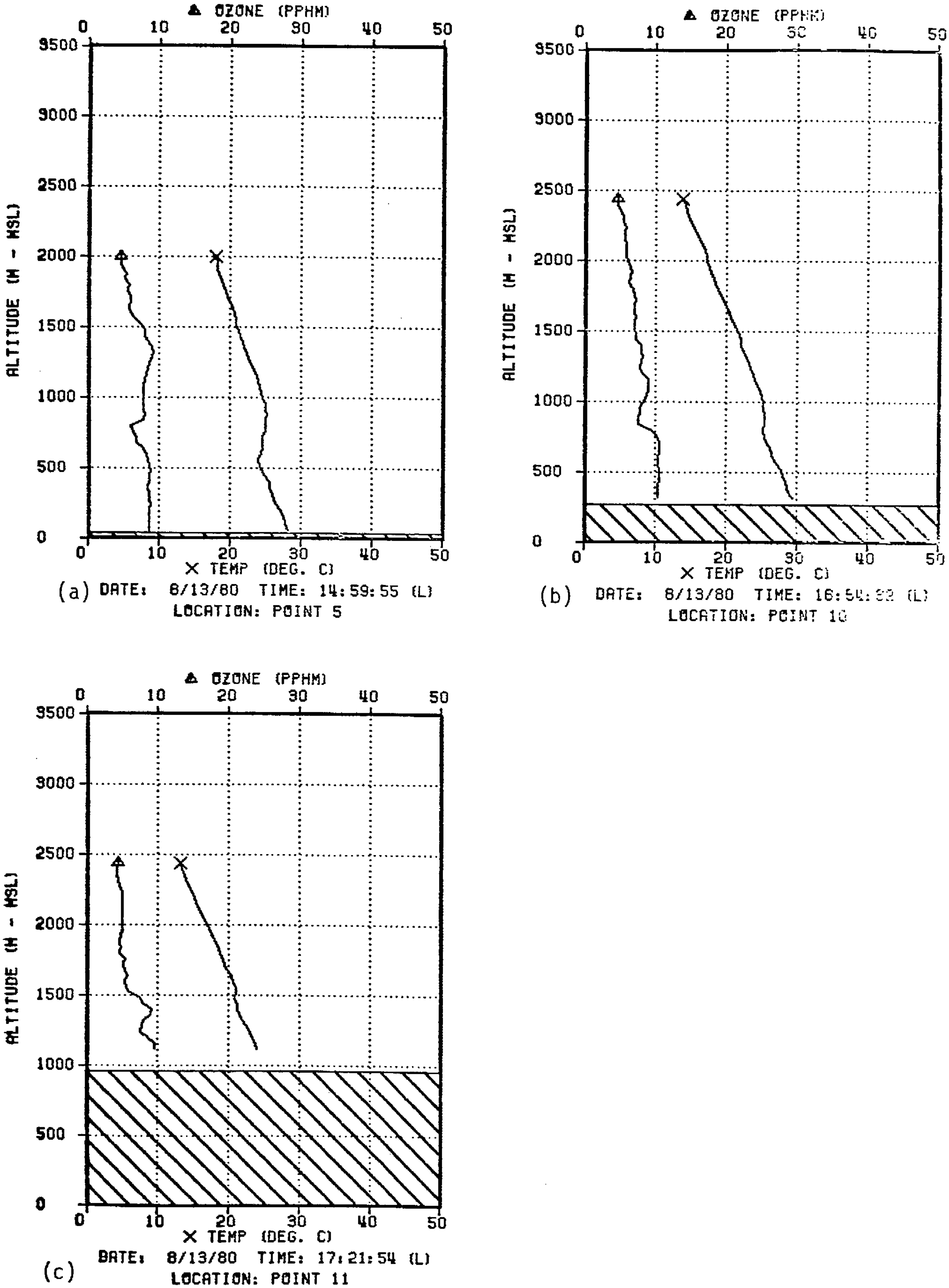


Figure 4.2.9 Temperature-Ozone Profiles over a) Lincoln AP, b) Big Oak Valley AP, and c) Nevada Co. AP. 13 August 1980.

Table 4.2.4 Summary of Aircraft Soundings - 13 August 1980

Location	Time (PDT)	Distance From Sacramento Exc.AP (km)	Mixing Ht. (m)	Average Ozone Concentration (pphm)	Ozone Loading Above Background* (mg/m^2)
Lincoln AP (Point 5)	1500	45	510	8.6	36.2
Big Oak Valley AP (Point 10)	1655	76	530	10.5	57.4
Nevada Co. AP (Point 11)	1722	89	550	8.5	37.9

*Background concentrations = 5 pphm

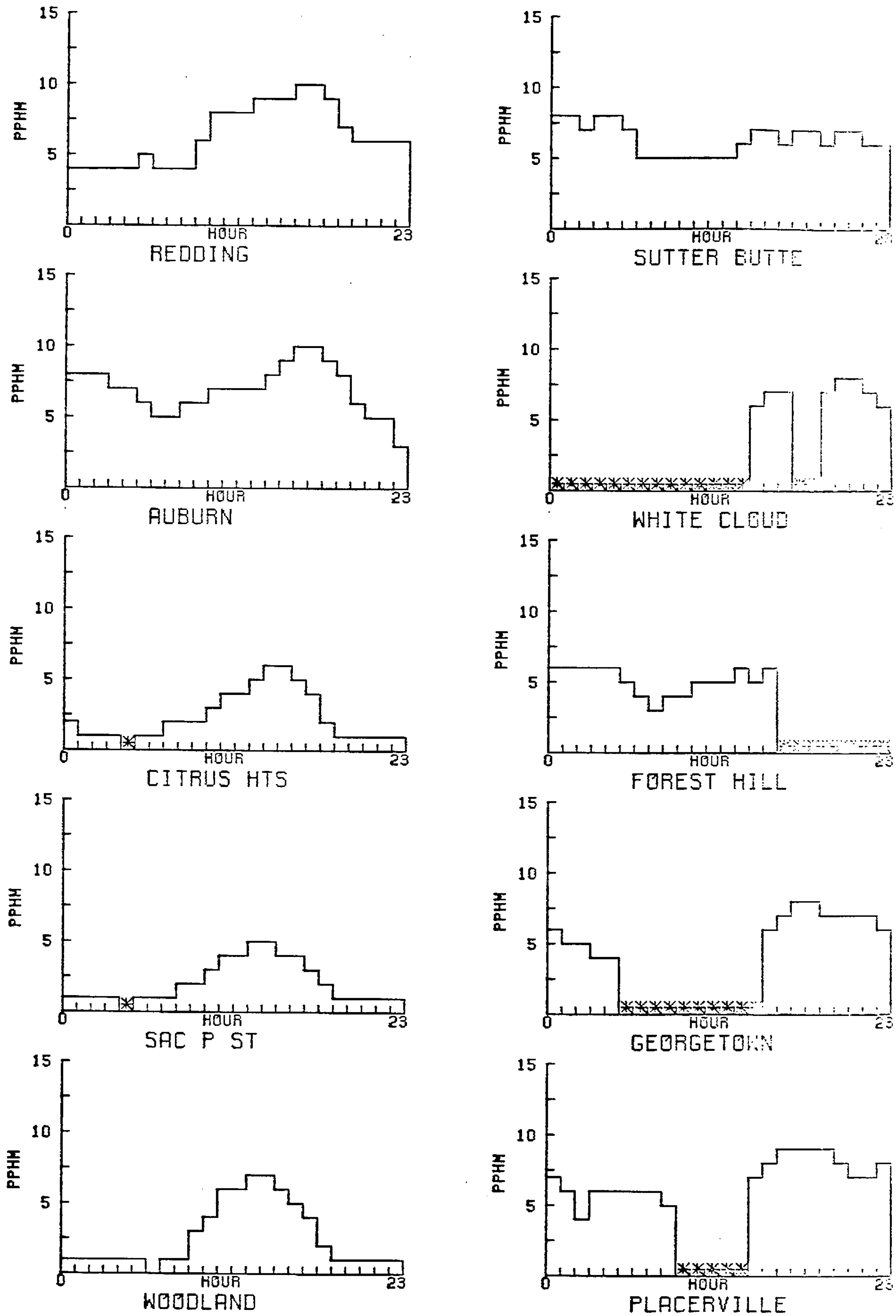


Figure 4.2.10 Hourly Averaged Oxidant Concentrations at Selected Locations. 13 August 1980. (* indicates missing data).

(10 pphm) and time of occurrence were the same for Redding and Auburn. The tracer data (discussed in the next section) indicate that pollutants from the Sacramento urban area may be transported to Marysville, Willows, Redding, and other locations in the Northern Sacramento Valley. However, wind velocities during this tracer test were strong, resulting in good dispersion and low pollutant concentrations throughout the valley.

4.2.3 Tracer Results

About 500 lbs of SF_6 were released continuously from 15th and R St. in Sacramento between 0600 and 1100 PDT. Automobile traverses showed that the SF_6 was transported directly north of the release site. The plume centerline was found between Rio Linda Boulevard and Northgate Boulevard on I-880. Another traverse showed that the plume centerline crossed the intersection of Marysville Road and Elkhorn Boulevard. These locations lie directly north of the release site. The SF_6 plume was about 2-4 miles wide on Elkhorn Boulevard between the locations corresponding to SF_6 levels 10% of the maximum level (max level > 1000 PDT). At this distance downwind of the release site (13 km), the horizontal dispersion coefficients of the plume (.5-1 mile, approx. 1/4 of the distance between locations corresponding to SF_6 concentrations 1/10 of the maximum) correspond to between A and C stability classification in the Gaussian plume model. Traverses between Marysville and Roseville on HWY 65 showed that the bulk of the SF_6 was transported towards the center of the Valley rather than up the slopes to the east of Sacramento. A high SF_6 level of 300-500 PPT was detected near Marysville. These levels were spread over a distance of about 10-15 miles. The width of the SF_6 plume suggests that the traverse was along the plume rather than perpendicular to it. Because the winds at Marysville were about 7-10 mph from the southeast, the next traverses were directed towards the northern half of the Sacramento Valley. Support personnel from Chico State University (in Chico) ran traverses that criss-crossed the northern half of the Valley between I-5 and HWY 99 and between Red Bluff and Oroville. CalTech personnel traversed the width of the Valley south of Oroville. An additional traverse along I-80 from the Lake Tahoe basin was used to detect any tracer that was transported in the weak upslope flow.

Hourly averaged SF_6 concentrations observed during Test 2 are shown in histogram form in Figure 4.2.11. The strong impact of the tracer northward in the Sacramento Valley is clearly shown. Concentrations in excess of 200 PPT were observed at Marysville. A peak concentration of 21 PPT was measured at Redding. The timing of the SF_6 at Redding indicated an average transport speed of 4 m/s from Sacramento to the extreme north end of the Valley.

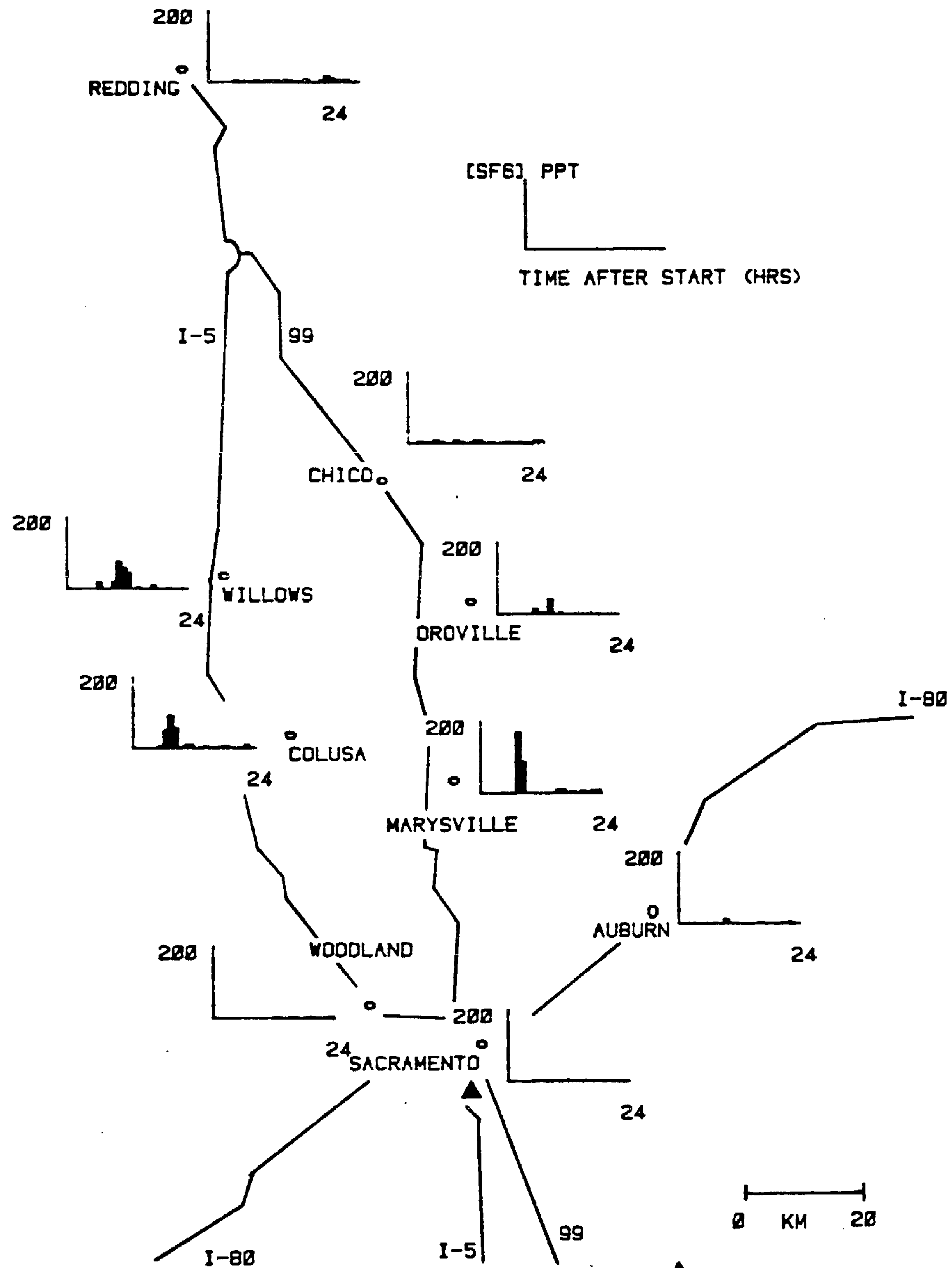


Figure 4.2.11 Hourly Average SF_6 Concentrations
Test 2 - August 13, 1980

The estimated trajectories of the SF_6 plume are shown in Figure 4.2.12. The principal plume moved northward past Marysville and Oroville toward Redding. A secondary plume was initiated early in the release under southeasterly winds and moved northwestward toward Colusa and Willows. There was some evidence of an afternoon trajectory from Sacramento into Auburn.

Auto traverses were made to the north and northeast of Sacramento on the following day (August 14) without observing significant amounts of tracer material.

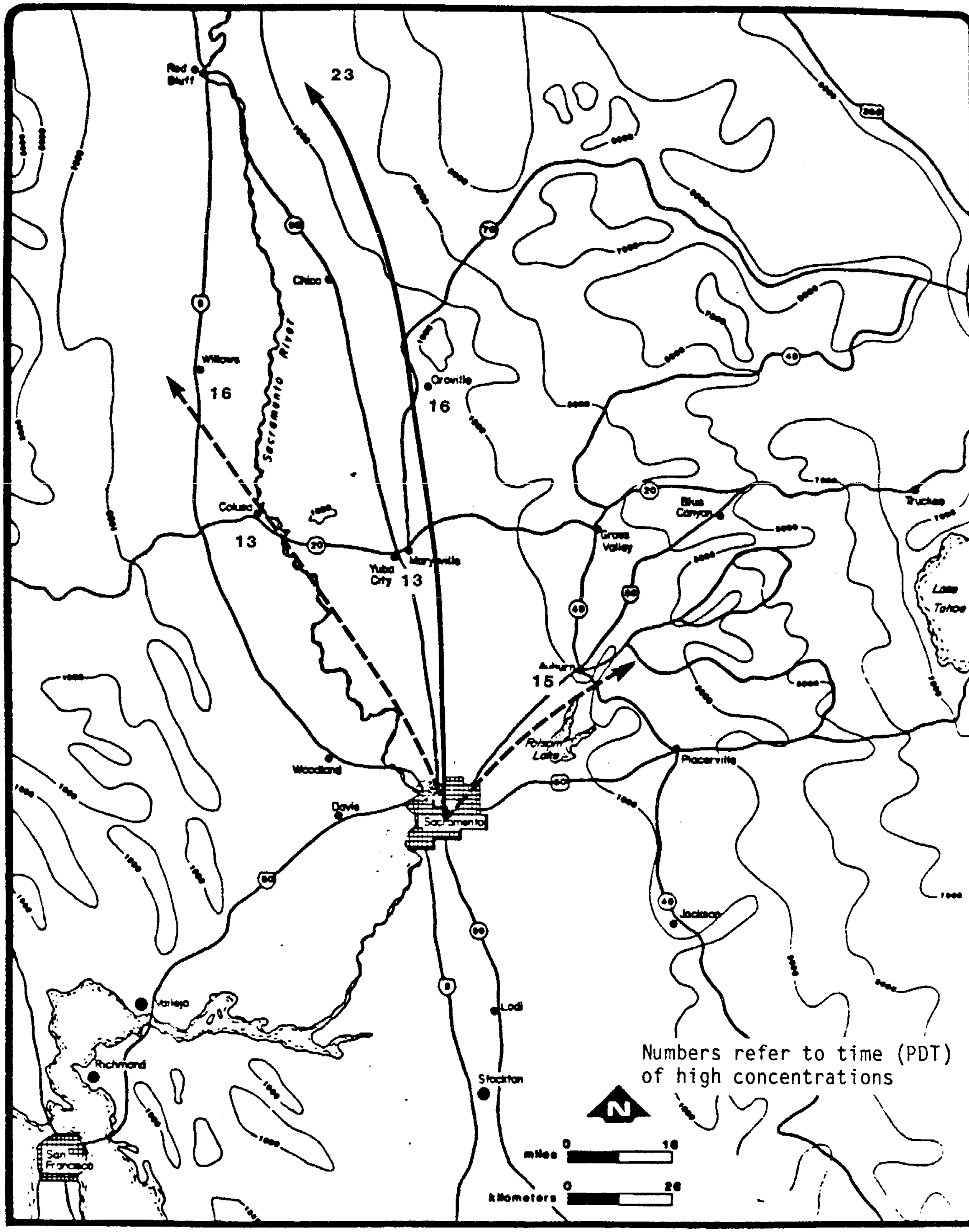


Figure 4.2.12 Tracer Trajectories - Test 2
August 13, 1980 - 0600-1100 PDT

4.3 Test 3 20-21 August 1980, Northeast Sacramento Release(1500-1900PDT)

4.3.1 Meteorology

General

This test was conducted during a brief stabilizing period between a series of upper level disturbances associated with a persistent long wave pattern which was causing unseasonably cool temperatures in Northern California. The August 850 mb temperature trend, plotted in Figure 2.4.3, shows even though a warming and stabilization trend had been established since the last trough passage on the 19th, temperatures nevertheless remained below the August normal. The weather charts for 0500 PDT, 21 August, are shown in Figure 4.3.1. On the 500 mb chart, Northern California lies in a zone of light winds but there is evidence of another disturbance developing offshore. However, at the surface, typical summertime conditions prevailed, characterized by clear skies and troughing over the interior of California. As can be seen from the data in Table 2.4.2, moderate pressure gradients existed between San Francisco and Sacramento although not as great as during the previous Sacramento release. The Sacramento to Red Bluff pressure gradient was lower than average for the period.

Skies were generally clear throughout the Sacramento Valley on the 20th. Surface temperatures in the south were near or slightly below the normal for August and a few degrees cooler than normal in the north. Highs ranged from 89^{o} at Sacramento to 92^{o}F at Redding and Red Bluff. By the afternoon of the 21st, middle clouds were reported in the north half of the Valley while scattered high clouds enveloped the entire region.

Mixing Heights and Vertical Stability

Temperature profiles for 20 and 21 August over Sacramento are shown in Figures 4.3.2 and 4.3.3, respectively. The stabilizing of the atmosphere on the 20th is evidenced by warming aloft at 1500 m (approximate 850 mb level) from 17^{o} to 19.5^{o}C. On the following day, temperatures at the 850 mb level remained between 19-20^{o}C suggesting constant synoptic meteorological conditions after the test was underway. Based on the temperature profiles and maximum surface values measured at Sacramento, surface mixing extended to between 1100-1400 m on the first day and 1000-

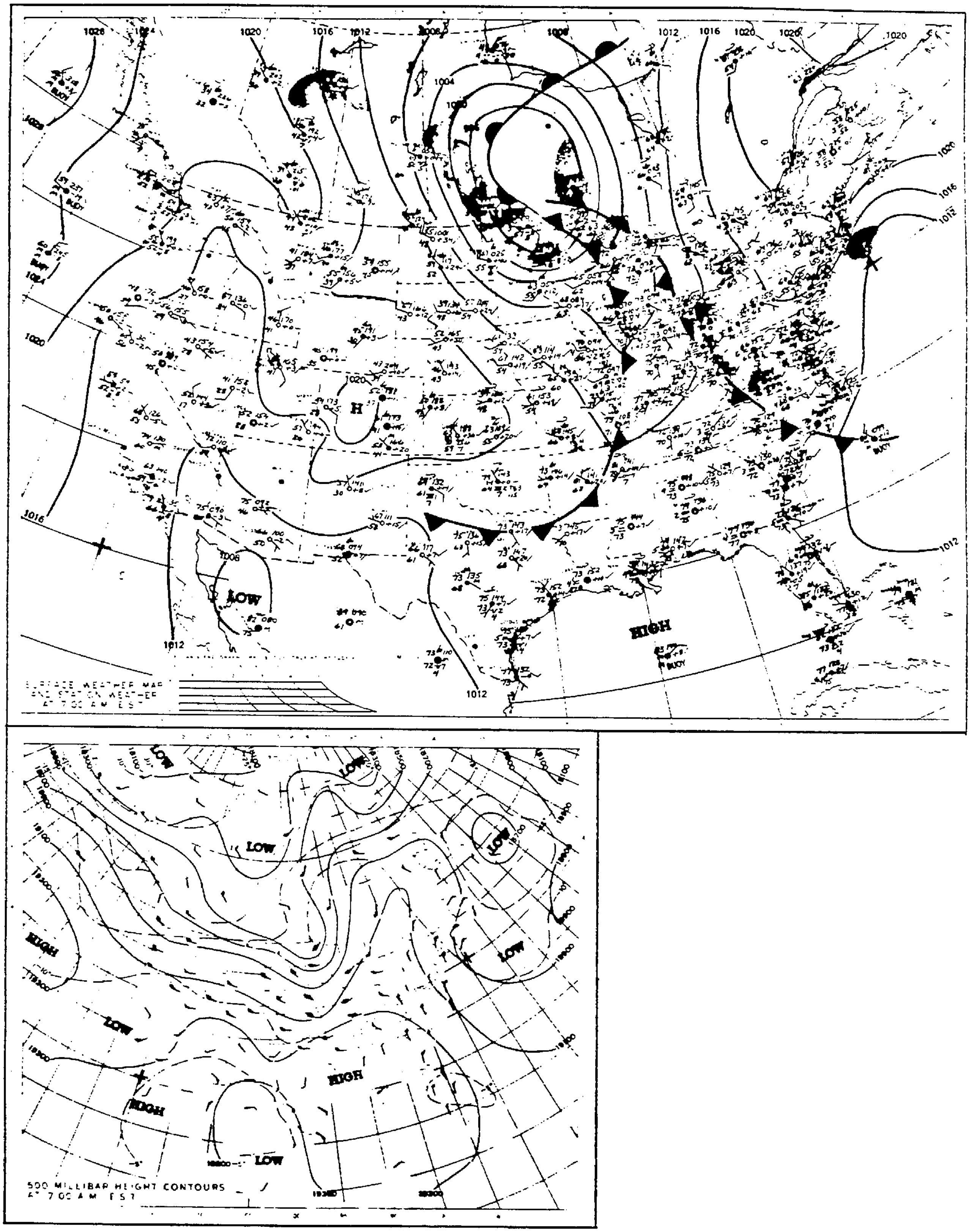
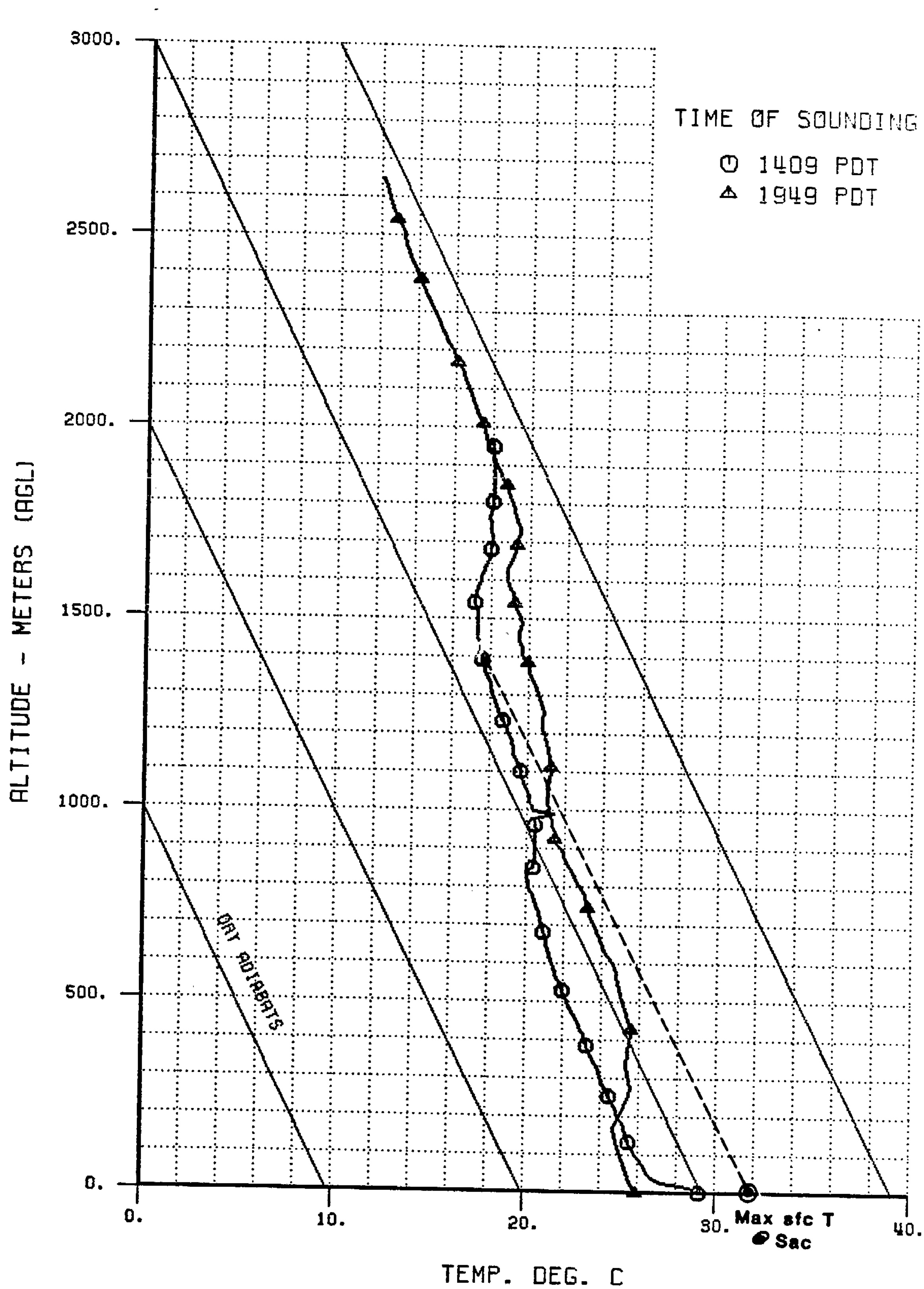


Figure 4.3.1 Surface and 500 mb Weather Charts - 21 August 1980 (0500 PDT)



LOCATION: SACRAMENTO MCC
DATE: 8/20/80

Figure 4.3.2 Temperature Profiles. Dashed line is potential temperature based on maximum surface temperature.

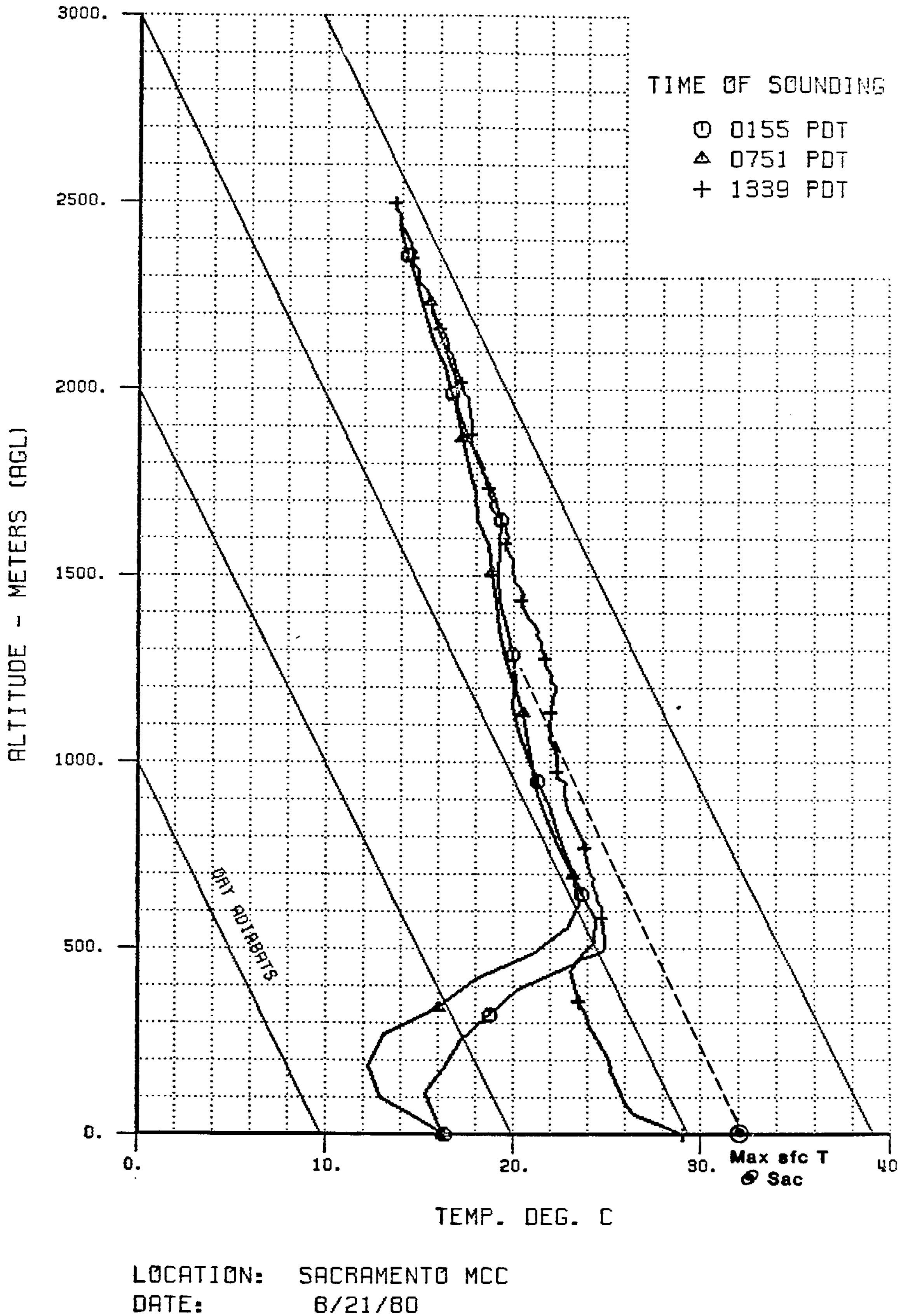


Figure 4.3.3 Temperature Profiles. Dashed line is potential temperature based on maximum surface temperature.

1300 m on the following day. At 08 PDT on the 21st, an 11°C nocturnal temperature inversion to 650 m was present.

Mixing heights as determined from the aircraft sampling on 20-21 August are summarized in Table 4.3.1. On 20 August, mixing ranged from 1000 m when surface heating was most intense to 750 m over the Sierra foothills later in the afternoon. On the following day, surface mixing extended to 800 m in the north at Red Bluff. Maximum surface temperatures were experienced later in the afternoon subsequent to the sounding at Red Bluff and hence mixing depths would have correspondingly increased.

Table 4.3.1

Aircraft Mixing Heights
20-21 August 1980

Time (PDT)	Location*	Mixing Height (m-agl)
20/0632	12 SE Sac Exec Airport	250
20/0726	Rio Linda Airport (10 NW Sac Exec)	250
20/1524	Sac Exec Airport	1000
20/1706	Phoenix Airport (Fair Oaks) (Pt. 4)	800
20/1808	Folsom Lake (Pt. 8)	850
20/1833	Auburn Airport (Pt. 9)	750
21/1120	5 SW Sac Exec Airport	400
21/1216	Marysville (24 N Sac Exec)	430
21/1409	4 S Red Bluff Airport	800

*Distance in miles (see Figure 4.3.6)

Transport Winds

Time-height cross sections of the pibal winds at Sacramento and Auburn are shown on Figures 4.3.4 and 4.3.5, respectively. During the afternoon of 20th the low level winds at Sacramento were from the southwest ranging from 1-3 m/s. In the presence of an otherwise light wind field, a

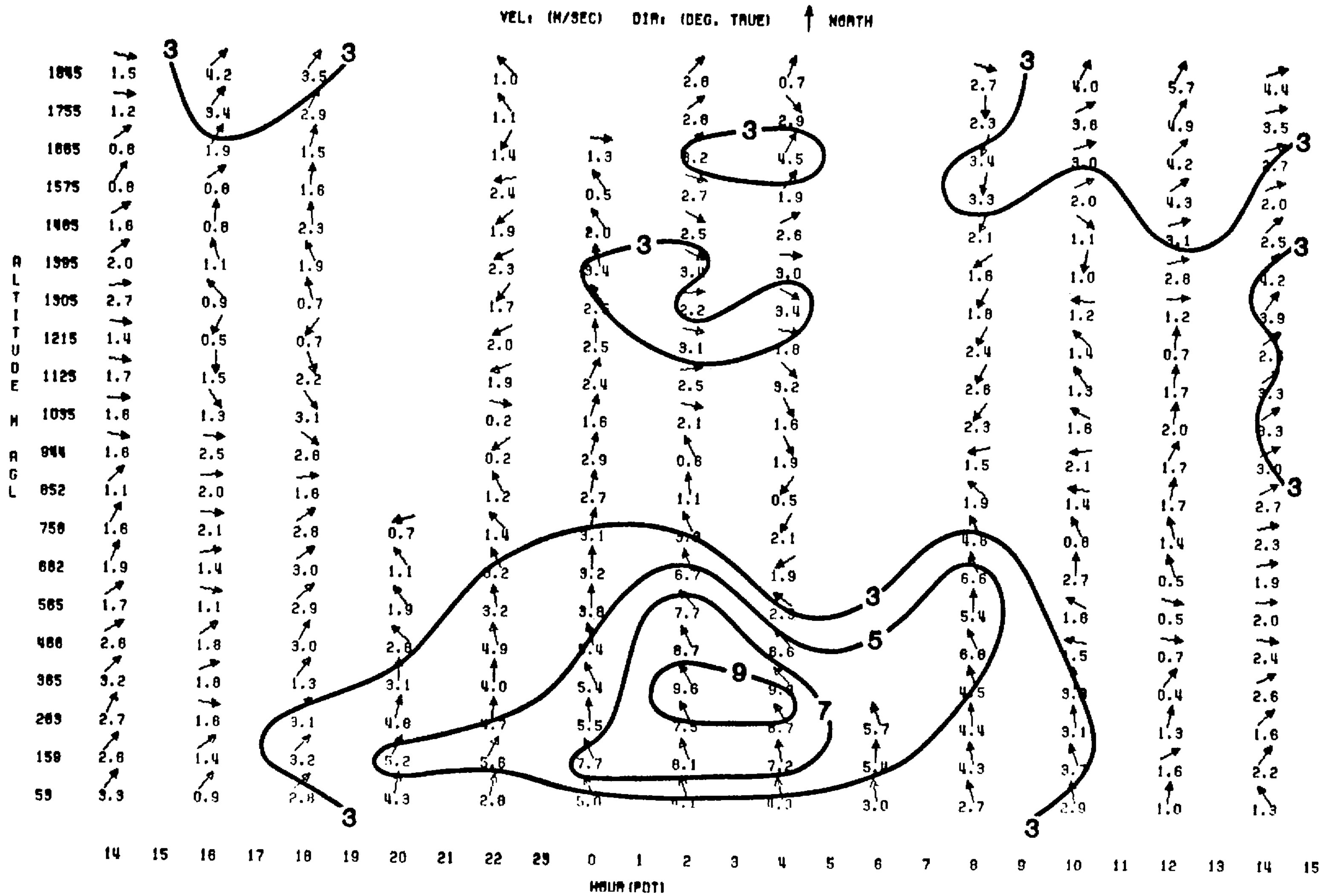


Figure 4.3.4 Vertical Time Section of Winds Aloft at N.E. Sacramento on 20-21 August 1980. Wind Speed in m/s.

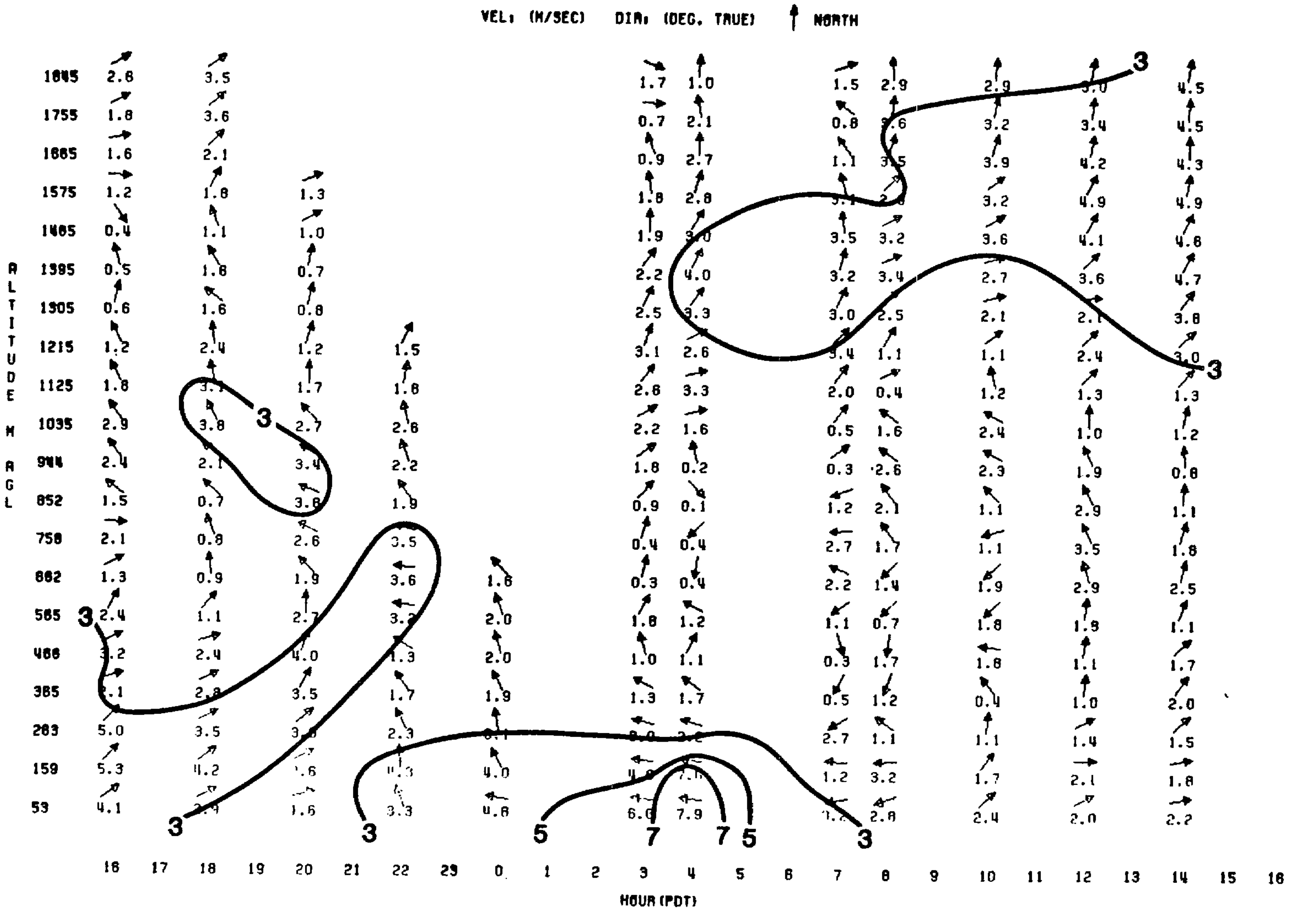


Figure 4.3.5 Vertical Time Section of Winds Aloft at Auburn on 20-21 August 1980. Wind Speed in m/s.

nocturnal jet is clearly observed developing in the evening of the 20th, reaching maximum strength of over 9 m/s between 02-04 PDT on the following morning. Maximum velocities were observed between 300-400 m-agl or below the top of the inversion. The surface winds during the afternoon and evening at McClellan AFB and White Cloud are tabulated in Table 4.3.2. McClellan AFB is approximately 3 km from the release site. The surface flows at McClellan differ from the flow aloft only in that they show a more southerly component. Wind speeds are generally comparable.

Table 4.3.2

Surface Winds at McClellan AFB and White Cloud RS
20 August 1980

Time (PDT)	McClellan Wind(m/s)	White Cloud Wind(m/s)
1500	230/2.0	240/2.9
1600	180/2.0	235/2.7
1700	210/2.6	245/2.2
1800	210/2.6	255/1.3
1900	210/3.1	295/0.7
2000	200/3.1	015/0.4
2100	210/3.1	030/0.7
2200	180/2.6	050/1.3
2300	150/4.6	035/1.1

At Auburn a southerly flow prevailed within the mixing layer until 2000 PDT on the 20th with speeds ranging between 2-5 m/s. A major feature of the Auburn time-height cross section is the development of strong low-level easterly winds coincident with the development of the southerly jet in the Valley. This suggests that in order to maintain mass balance, low-level air from the adjacent airshed is entrained horizontally into the nocturnal jet. Further implied is that air (Sacramento plume) earlier transported from the Valley into the Sierra foothills can feed the nighttime jet and be effectively transported northward to impact distant regions of the Sacramento Valley.

The winds aloft and at the surface from White Cloud showed a strong upslope flow (2-6 m/s) in the afternoon. By 2000 PDT a weak downslope flow developed which persisted throughout the night. There was no evidence of any influence from the jet on the wind field although the drainage flow off the Sierra slopes must ultimately impact the foothill region.

4.3.2 Air Quality

Airborne Sampling - 20 August

A discussion of the morning sampling is included in Section 3.3 of this report. Maximum ozone was measured between 850-1100 m above the ground in concentrations of about 8 pphm.

The afternoon airplane sampling route is depicted in Figure 4.3.6. Due to the light winds reported prior to takeoff, the airplane initially flew in a box pattern around Sacramento to determine the movement of the urban plume. When it became apparent that the flux was to be northeast, sampling began downwind beginning with a sounding at Fair Oaks (Point 4) and culminating with a traverse between Spenceville and Placerville (Point 10-11), roughly 45 km from the tracer release site (at the shortest distance). Traverses were flown at two altitudes between Lincoln and Cameron Park (Point 6-7) approximately 27 km downwind. All traverses were flown within the mixing layer. Spirals were also flown over Folsom Lake (Point 8) and Auburn (Point 9). The last three spirals were within the horizontal boundary of the urban air. Table 4.3.3 summarizes pollutant concentrations measured during each segment of sampling.

The ozone and temperature profiles obtained by the aircraft are shown on Figure 4.3.7. The major features of the soundings are summarized below in Table 4.3.4. This table shows the mixing height, average ozone concentrations within the mixing layer, and the integrated column content of ozone above background levels from the surface to the top of mixing. Included in the table is the distance downwind of each sampling location relative to Point 1, Sacramento Executive Airport. The distances that the column of air sampled over Point 1 would have been transported based on the mean winds and the sampling times are also included in the table. Comparing these distances, it is clear the same parcel of air was not measured. Nevertheless, it is apparent that ozone burden within the mixing layer increases with distance downwind of

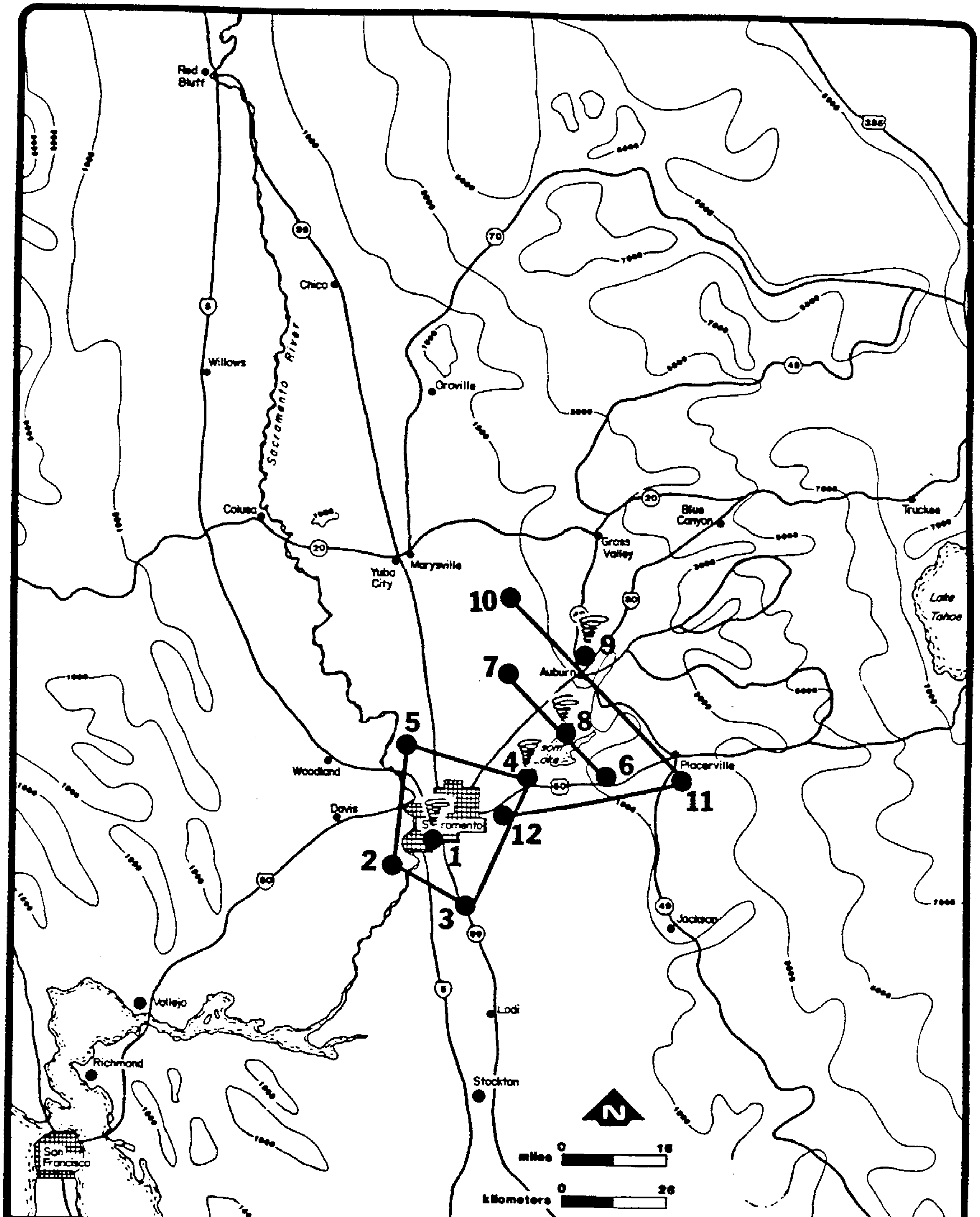


Figure 4.3.6
Sacramento Valley Oxidant Study
MRI 206 Sampling Flight Map

TEST 3 20 August 1980 Tape #151

Table 4.3.3

AIR QUALITY MEASUREMENTS CARB SACRAMENTO VALLEY PROJECT
AUGUST 20, 1980 SAMPLING

Start Time (PDT)	Location (Point)	Altitude (m-msl)	O_3 Mean (ppb)	O_3 Max (ppb)	b_{scat} Mean ($x10^{-6}m^{-1}$)	b_{scat} Max ($x10^{-6}m^{-1}$)	NO_x Mean (ppb)	NO_x Max (ppb)	NO Mean (ppb)	NO Max (ppb)	SO_2 Mean (ppb)	SO_2 Max (ppb)
1524	1	18-1829	74	96	79	163	3	17	2	7	1	2
-	-	-	-	-	-	-	-	-	-	-	-	-
1605	2-3	457	88	93	118	172	2	5	1	3	2	4
1615	3-4	457	94	114	121	163	3	7	1	3	1	3
1626	4-5	457	91	114	121	183	5	12	1	4	1	3
1639	5-2	457	88	96	116	183	4	7	1	4	1	3
1706	4	88-2134	80	111	87	163	5	12	1	5	0	2
1735	6-7	610	102	124	120	179	6	13	1	5	1	3
1751	7-6	914	100	120	122	185	6	13	1	4	1	3
1808	8	140-2134	85	124	95	181	6	12	1	4	1	2
1833	9	2286-475	89	128	106	192	3	7	1	4	0	2
1900	10-11	914	114	127	127	194	5	10	1	4	1	3
1923	11-12	914	96	114	112	158	6	10	1	3	1	2

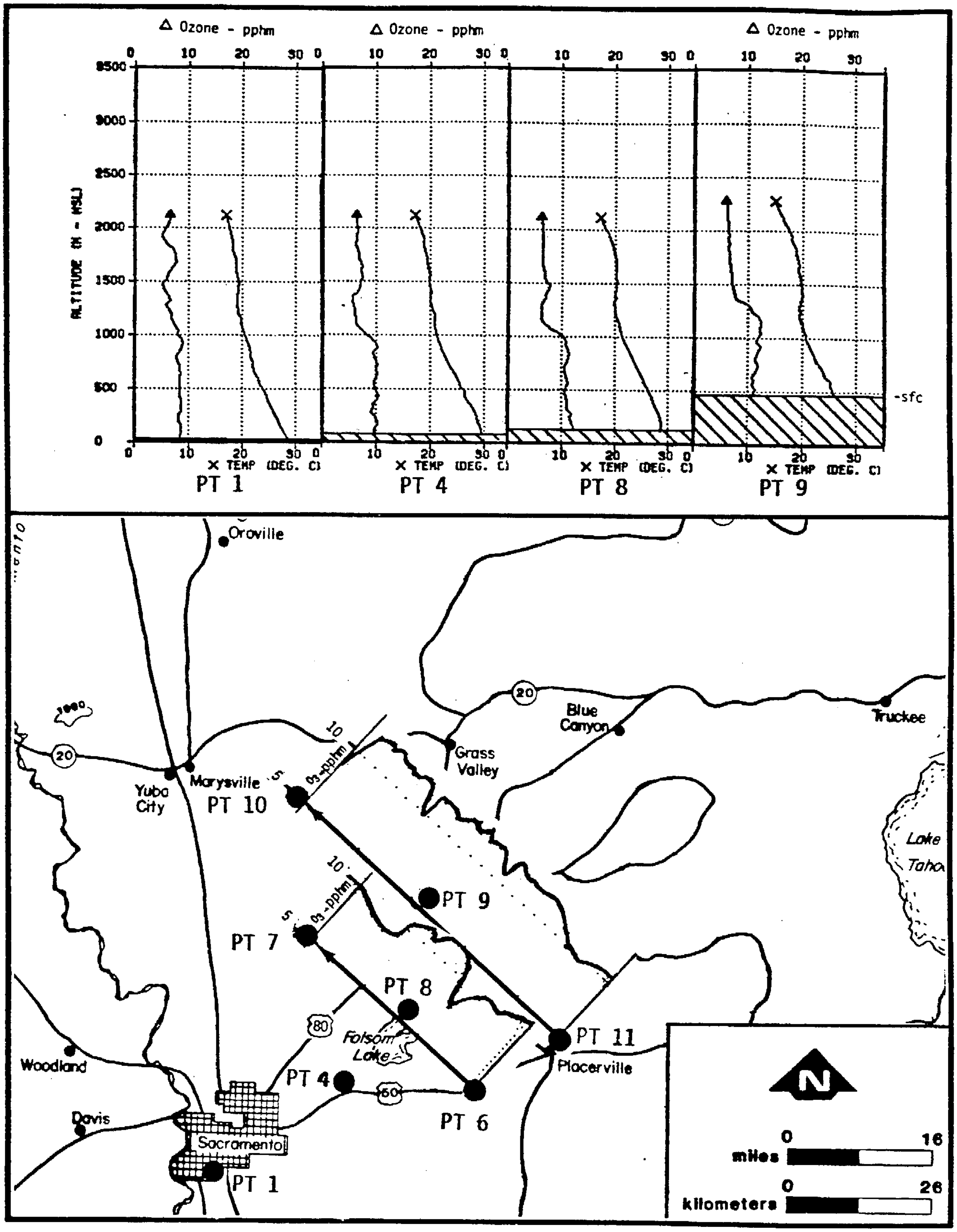


Figure 4.3.7 Aircraft Sampling 20 August 1980. Top: Temperature-Ozone Profiles over Sacramento, Fair Oaks, Folsom Lake, and Auburn (left to right). Bottom: Ozone Distribution along Traverses 27 km and 45 km downwind of Sacramento.

Table 4.3.4 Summary of Aircraft Soundings - 20 August 1980

Location	Time (PDT)	Distance (Km)		Mixing Ht. (m-agl)	Average Ozone Concentration (pphm)	Ozone Loading Above Background* (mg/m^2)
		Actual	Wind Run			
Sacramento (Point 1)	1534	0	0	1000	8.5	39.4
Fair Oaks (Point 4)	1715	29	13	800	9.9	53.6
Folsom Lake (Point 8)	1817	43	22	850	11.0	75.4
Auburn (Point 9)	1840	60	25	750	11.6	75.4

*Background concentrations = 6.5 pphm

Sacramento reflecting the photochemical reaction time to produce this secondary pollutant. Transport winds, which were from the southwest, assure that the major impact from these processes will be removed from the source region. Because NO_x concentrations simultaneously measured were relatively low (<1 pphm), it is inferred that the Sacramento urban air is hydrocarbon rich with a small amount of NO_x to trigger the sequence of photochemical smog reactions. The maximum hourly average ozone concentration measured at the surface at Auburn was 12 pphm during the period 18-1900 PDT which corresponds to the time of the aircraft spiral at that location. Figure 4.3.7 also depicts the ozone concentrations measured on the 3000 ft-msl aircraft traverses at the 27 and 45 km downwind distances. The Point 7 to Point 6 traverse (27 km) shows a distinct ozone plume from near Interstate 80 to the south shore of Folsom Lake. Ozone levels, after falling off substantially south of Folsom Lake, increased again near Cameron Park. Maximum concentrations were 12 pphm near the north shore of Folsom Lake (Point 8). Further downwind in the Sierra foothills (Point 10 to Point 11), the plume became more widely dispersed but levels in excess of 11 pphm were measured from near Spenceville (Point 10) south to Placerville. The transport of the urban plume out of the source region was substantiated on the traverse back to Sacramento from the foothills (Point 11 to Point 12). Ozone concentrations dropped off rapidly near El Dorado Hills, decreasing to 7 pphm over the city.

Due to light transport winds and the late timing of the release, the only tracer detected was within the mixing layer over Fair Oaks (Point 4).

Airborne Sampling - 21 August

The flight route on the following day is shown on Figure 4.3.8. Sampling was conducted from 1120 to 1530 PDT. The flight consisted of a set of three spirals and horizontal traverses north along the east side of the Valley to Red Bluff, followed by traverses south along the west side. One traverse was flown roughly perpendicular to the Valley axis near Marysville. Table 4.3.5 summarizes the pollutant concentrations measured during each segment of sampling.

Profiles of temperature and ozone concentrations measured on the spirals are shown on Figure 4.3.9. Noteworthy are the high ozone concentrations measured at Marysville and Red Bluff. On the Red Bluff sounding, efficient mixing is observed from the surface to 800 m-agl with ozone concentrations averaging over 10 pphm. The sounding near Marysville, taken two hours earlier, still reflects the remnants of the nocturnal inversion. The ozone reservoir aloft between 500 and 1000 m with concentations in excess of 10 pphm is of special interest since tracer material was also found to be present during post-test analysis. At the time, however, it was the presence of the high ozone aloft which prompted a cross valley traverse at 760 m-msl (Point 3 - Point 4). Ozone and SF_6 measurements along that traverse are shown in Figure 4.3.10. This figure shows that high ozone concentrations are associated with high SF_6 measurements, indicating that the ozone-rich air was "tagged" with tracer material released from Sacramento. Ozone concentrations in excess of 10 pphm were measured across a wide zone beginning near the Sacramento River on the west and extending nearly to Englebright Reservoir (Point 4) in the eastern foothills. Maximum ozone concentrations (12 pphm) were measured over Beale AFB about 10 km east of Marysville. Tracer material was found along 40 km of the traverse with maximum concentrations near Marysville-Yuba City. Ozone concentrations between 9-11 pphm were measured along the remainder of the sampling north to Red Bluff. Varying amounts of tracer material were also detected to Red Bluff.

Had the Sacramento plume been transported in a homogeneous manner over Marysville, the ozone profile might be explained by scavenging below the nocturnal inversion with increased ozone aloft as a result of mixing processes that occurred on the previous day. However, the detection of tracer only in the 500-1000 m layer infers that the air above and below the

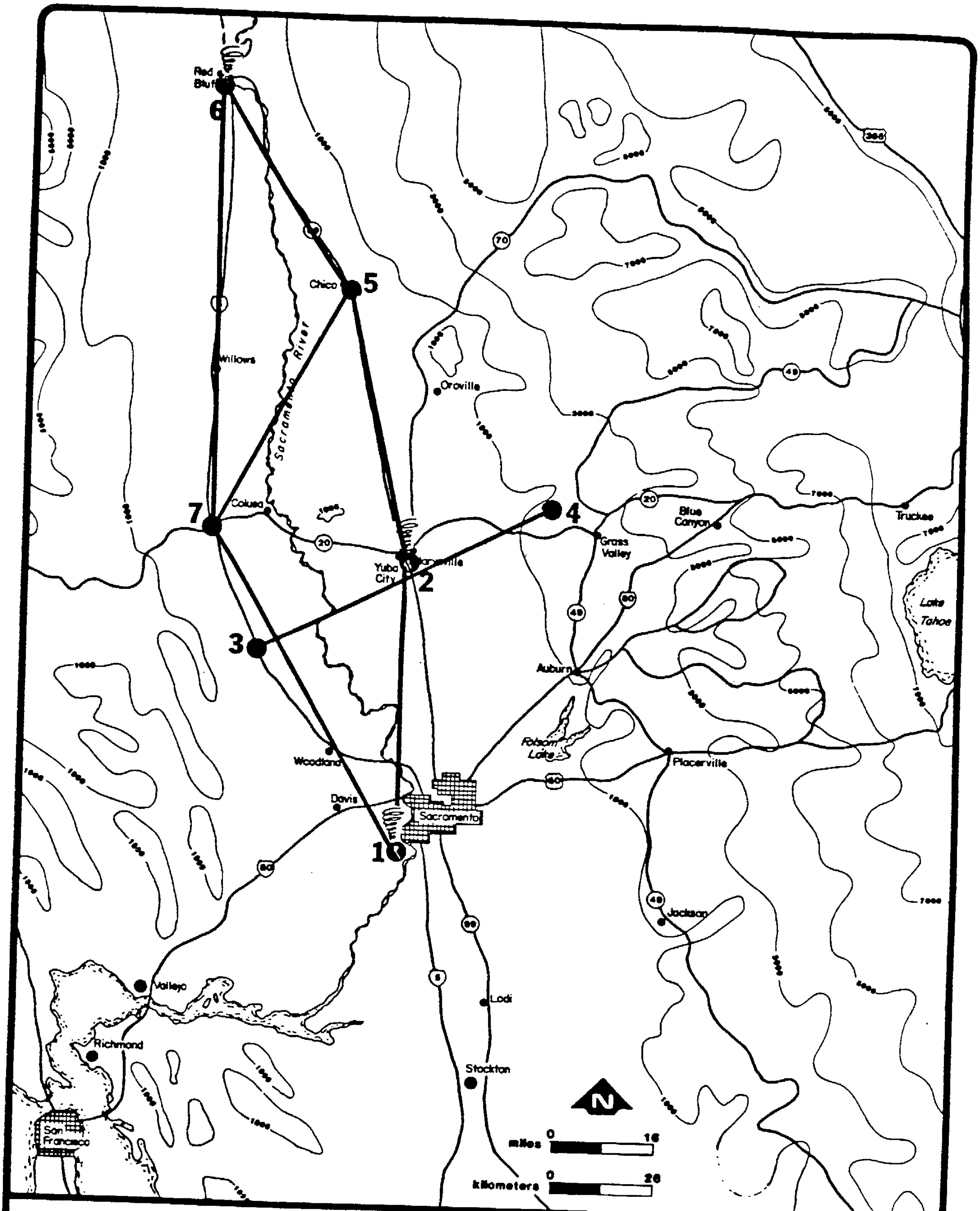


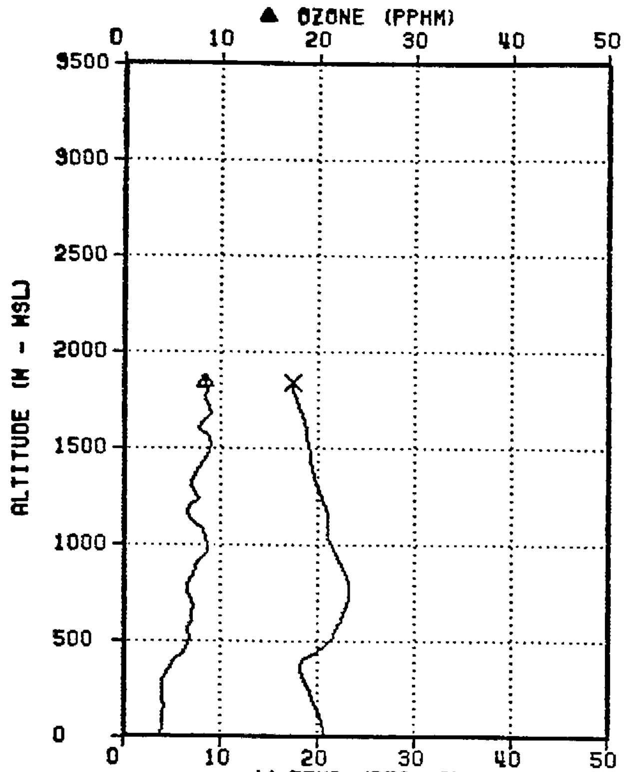
Figure 4.3.8
Sacramento Valley Oxidant Study
MRI 206 Sampling Flight Map

TEST 3 21 August 1980 Tape #152

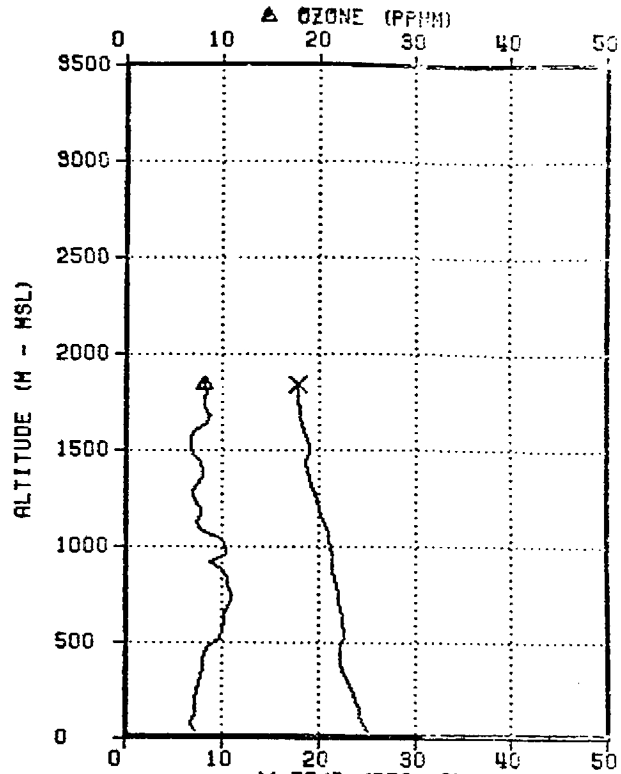
Table 4.3.5

AIR QUALITY MEASUREMENTS CARB SACRAMENTO VALLEY PROJECT
AUGUST 21, 1980 SAMPLING

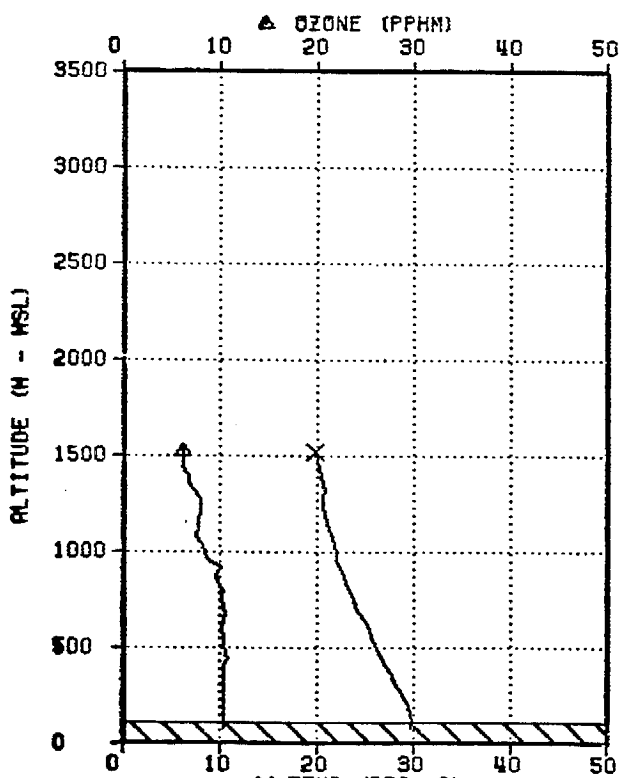
Start Time (PDT)	Location (Point)	Altitude (m-msl)	O_3 Mean (ppb)	O_3 Max (ppb)	b_{scat} Mean ($\times 10^{-6} m^{-1}$)	b_{scat} Max ($\times 10^{-6} m^{-1}$)	NO_x Mean (ppb)	NO_x Max (ppb)	NO Mean (ppb)	NO Max (ppb)	SO_2 Mean (ppb)	SO_2 Max (ppb)
1120	1	9-1829	71	94	81	147	5	17	2	8	1	3
-	-	-	-	-	-	-	-	-	-	-	-	-
1153	1-2	305	56	87	148	289	18	40	6	13	3	4
1216	2	24-1829	84	115	110	215	8	19	2	8	1	2
1248	3-4	762	98	117	106	181	6	15	3	8	1	2
1329	2-5	457	96	123	140	330	10	31	3	8	2	3
1353	5-6	457	99	109	132	197	9	17	2	7	2	3
1409	6	114-1524	92	110	94	170	9	18	3	10	1	3
1427	6-7	610	94	109	115	206	7	16	3	10	3	4
1507	7-1	610	79	92	105	181	9	21	3	9	4	8



(a) DATE: 8/21/80 TIME: 11:19:49 (L)
LOCATION: POINT 1



(b) DATE: 8/21/80 TIME: 12:15:53 (L)
LOCATION: POINT 2



(c) DATE: 8/21/80 TIME: 14: 9:27 (L)
LOCATION: POINT 6

Figure 4.3.9 Temperature-Ozone **Profiles** over a) 5 mi SW Sacramento Exec. AP, b) Marysville, and c) Red Bluff. 21 August 1980.

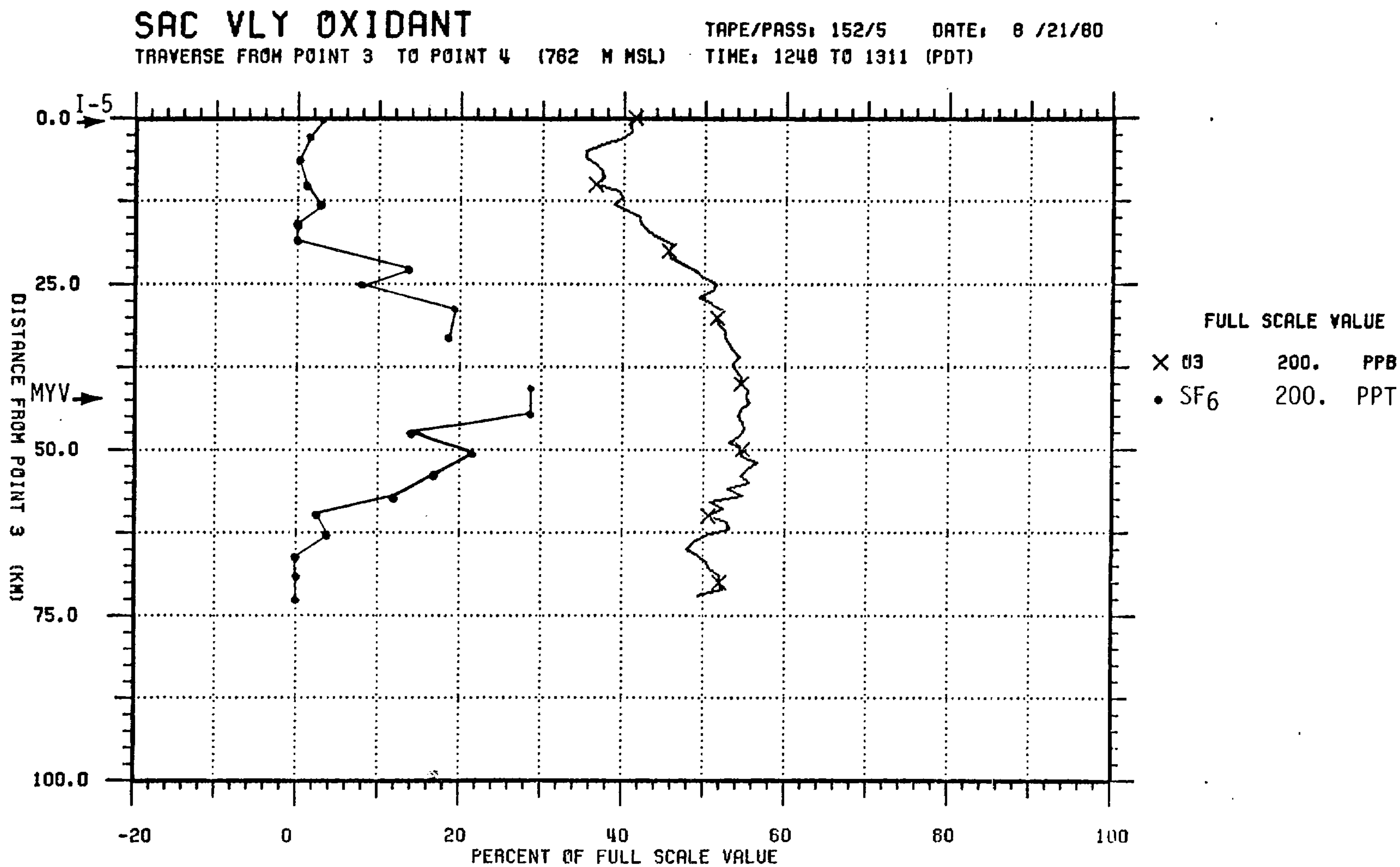


Figure 4.3.10 West-East Airplane Traverse from Point 3 to Point 4 (refer to Figure 4.3.6), 762 m-msl. 21 August 1980. Showing O_3 and Tracer concentrations.

nocturnal inversion had differing histories. An inspection of the winds aloft at Sacramento, in particular the nocturnal jet, supports this inference. The profile of the average wind component along the Valley axis, derived from the 20/1400 - 21/1200 PDT Sacramento pibals, is shown on Figure 4.3.11. This period approximates the start of the tracer release to the time of the aircraft sounding at Marysville. From the figure, the contribution to low-level transport by the nocturnal jet is clearly evident. Using the average of wind components within layers, wind runs of 148 mi and 37 mi calculated for the layer below 500 m and for the 500-1000 m layer, respectively. The distance from the release site to the Yuba Co. Airport is 34 mi (115 mi to Red Bluff). Thus the tracer plume below 500 m was transported a long distance upvalley whereas material mixed to greater depths was transported only a relatively short distance.

Regional Surface Oxidant Levels

Hourly averaged surface ozone concentrations for selected locations within the study area are shown in Figure 4.3.12. Exceedances of the State standard were experienced at Auburn for 2 hours. The movement of the urban plume northeast through Citrus Heights to Auburn can be readily discerned from the figure by noting the progressively later timing of maximum ozone concentrations. Peak levels of 12 pphm were measured between 17-1800 PDT at Auburn; within an hour of the airplane sampling and in excellent agreement with those measurements.

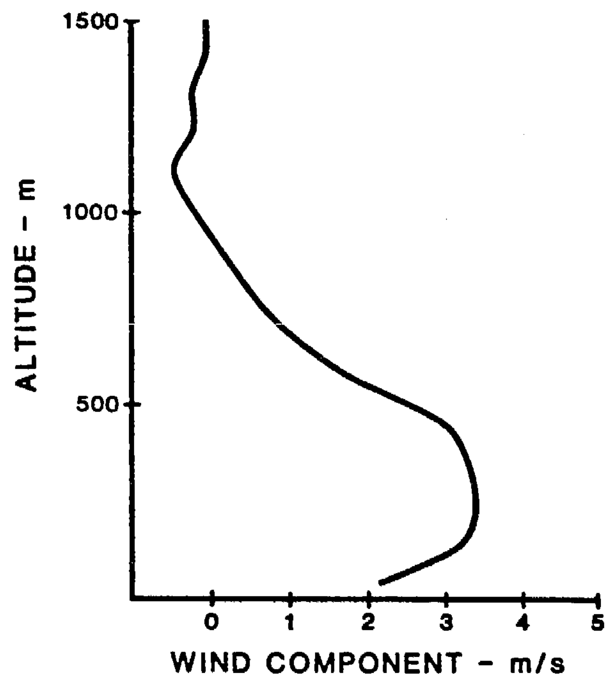


Figure 4.3.11 Average Wind Component Along Valley Axis. 20-21 August 1980 at Sacramento. Positive Component is Flow Upvalley, i.e., From Sacramento Towards Redding.

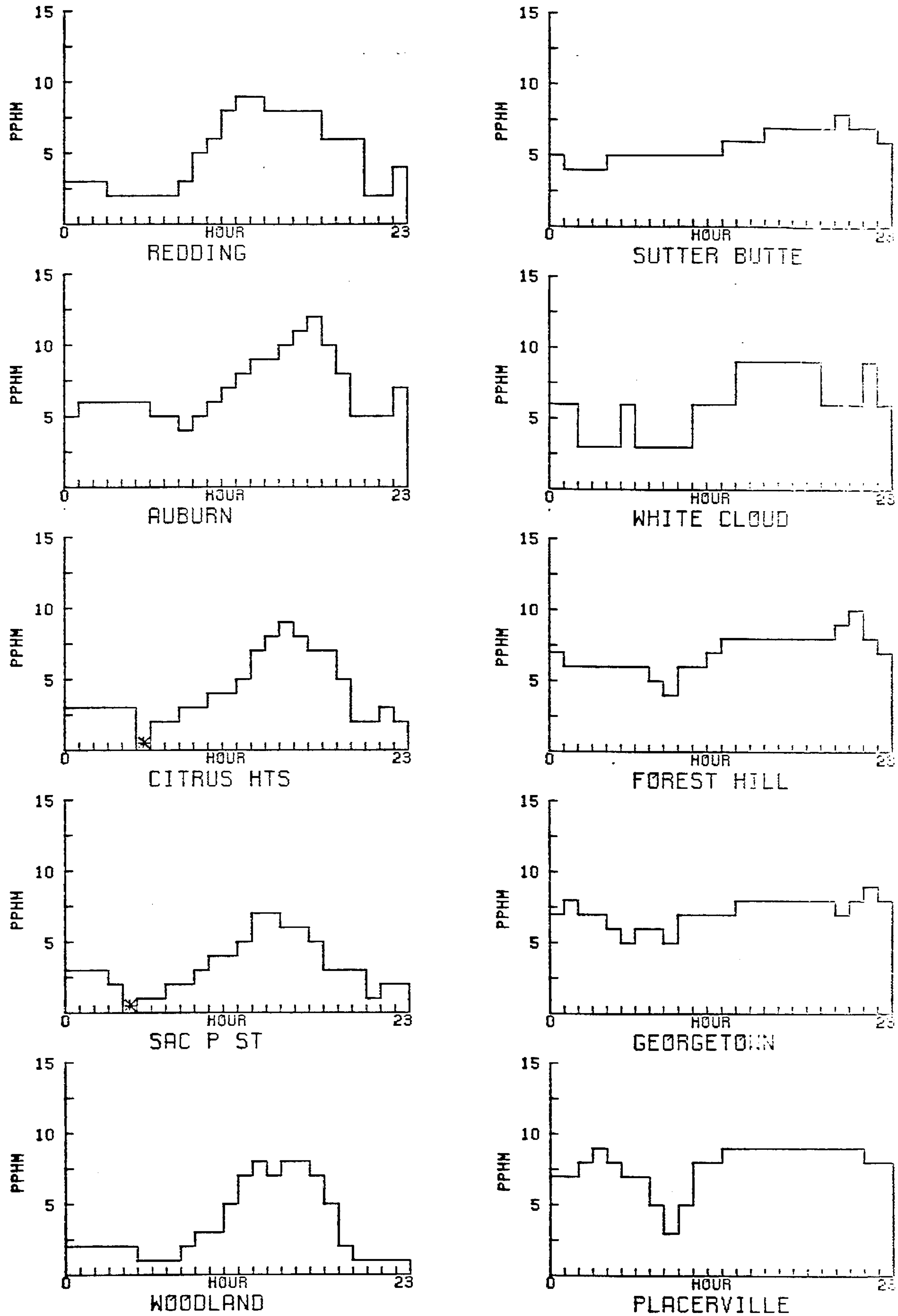


Figure 4.3.12 Hourly Averaged Oxidant Concentrations at Selected Locations. 20 August 1980. (* indicates missing data).

4.3.3 Tracer Results

About 400 lbs. of SF_6 were released continuously from a location south of McClellan AFB between 1500 and 1900 PDT on August 20, 1980. Auto traverses showed that the SF_6 was initially transported east of the release site between Auburn and Placerville. Neither of the hourly samples at these locations indicated significant concentrations, however. Figure 4.3.13 shows the concentrations measured along Highway 49 between Auburn and Placerville and along the Auburn-Folsom road during the early evening. As indicated in Table 4.3.2 the upslope surface winds at White Cloud terminated between 1900 and 2000 PDT and the upslope movement of the tracer material should also have been ended.

The trajectory of the plume as indicated by the surface SF_6 observations is shown in Figure 4.3.14. No further evidence of significant surface concentrations was found on August 20.

On the following morning substantial amounts of SF_6 were found aloft by the aircraft over the Valley to the north of Sacramento. These data were obtained between 450 and 750 m (msl) altitude and are plotted in Figure 4.3.15. The insert figure shows a vertical profile of the SF_6 concentrations at Marysville. The aircraft tracer data on August 21 can account for a majority of the material released on the preceding day.

Surface auto traverses were also made on August 21. The only significant concentrations observed were obtained near Roseville about 1000 PDT.

Hourly SF_6 concentrations at Marysville and Chico increased abruptly at about 1300-1400 PDT. It is suggested that these concentrations result from fumigation of the previously observed tracer material aloft to the ground as a result of a diurnal increase in vertical mixing.

The foregoing discussion can be summarized as follows:

-In the afternoon, the Sacramento urban plume impacted northeast of the city, most severely in the Sierra foothills along a broad zone extending from near Placerville north to near Highway 20.

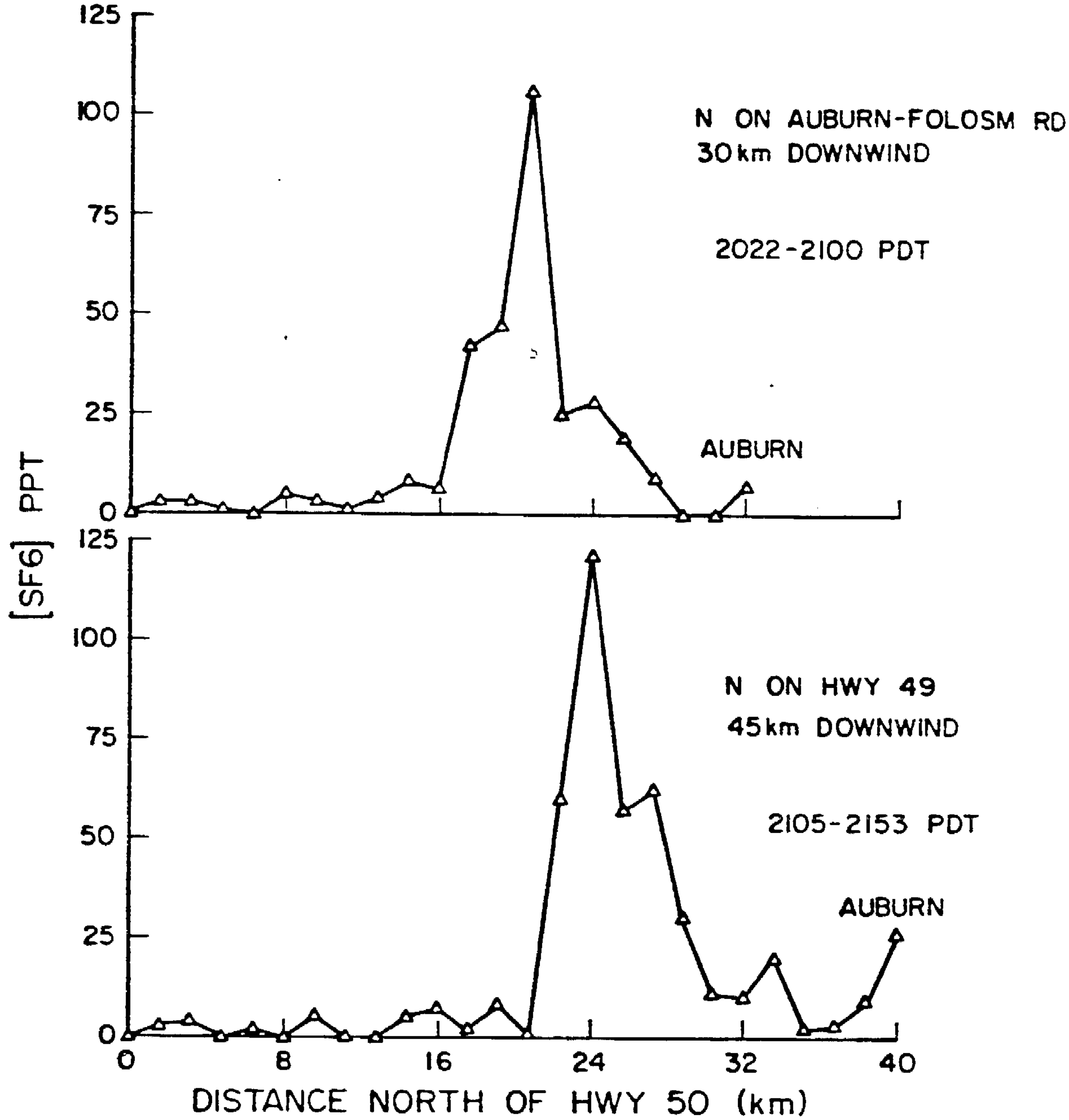


Figure 4.3.13 SF_6 Tracer Concentrations from Automobile Traverses in the Sierra Foothills Test 3 - August 20, 1980.

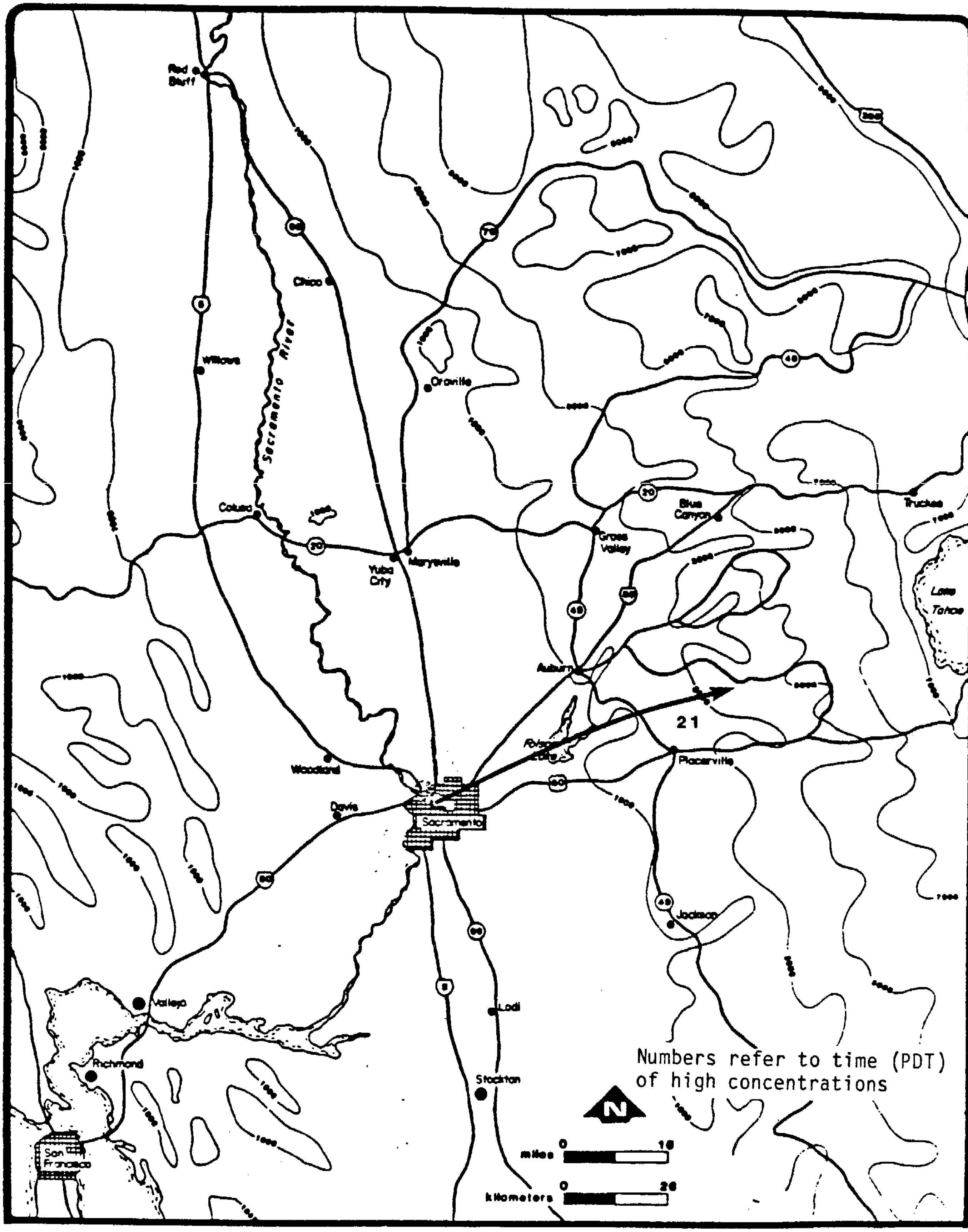


Figure 4.3.14 Tracer Trajectories - Test 3
August 20, 1980 - 1500-1900 PDT

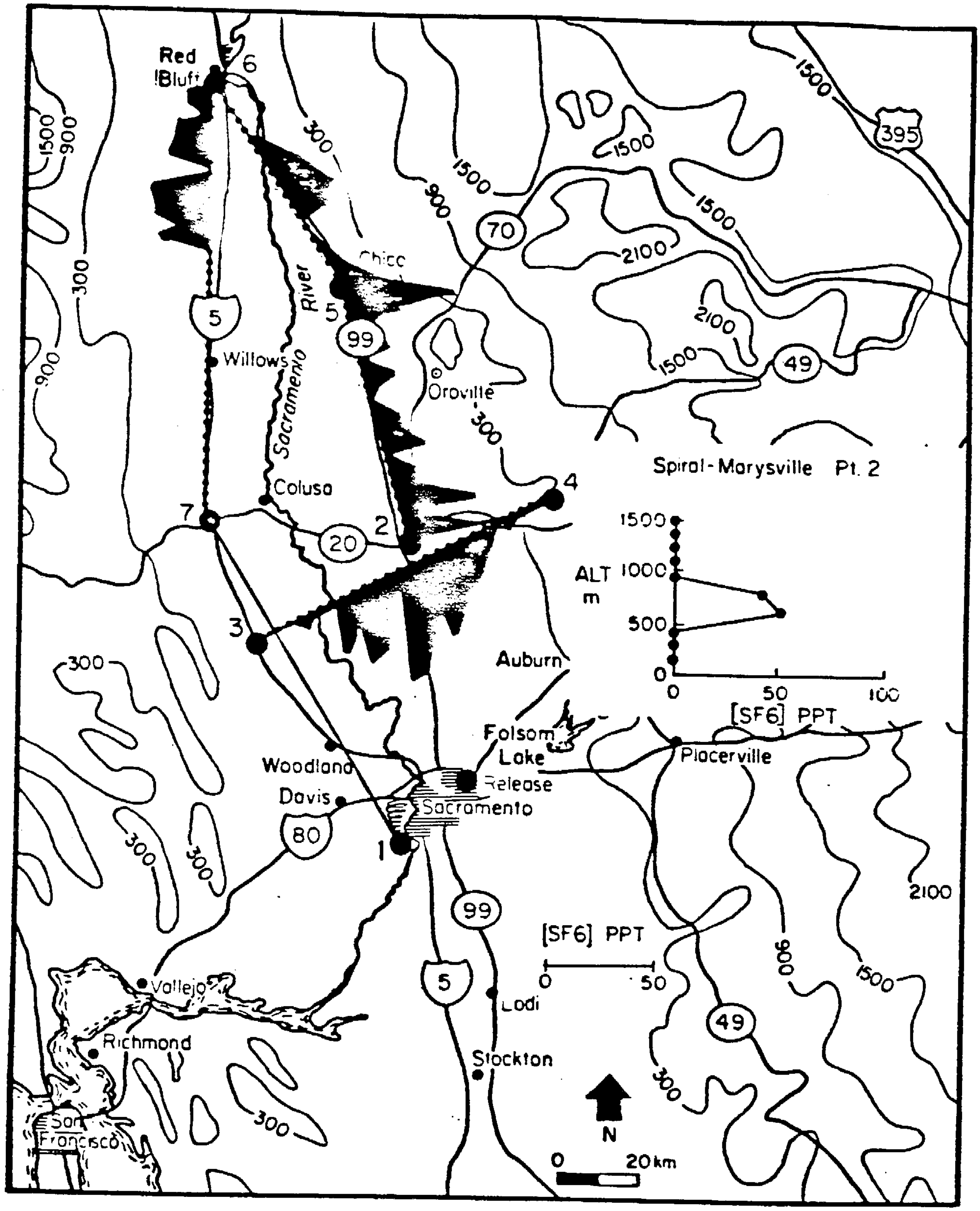


Figure 4.3.15 SF_6 Concentrations from Aircraft Traverses (day after release) Test 3 - August 21, 1980

-Ozone concentrations within the urban plume progressively increased downwind with levels in excess of 12 pphm measured as far as 135 km from the downtown area.

-By the onset of drainage flows in the mountains, the bulk of the urban plume had been transported into the foothill region but a large portion still remained along the eastern edge of the Valley.

-During the late evening and early morning, low level air which had just previously been transported from the urban source to the foothill region may be drawn back into the Valley and entrained into the nocturnal jet. The jet is then capable of effectively transporting the pollutants north over large distances.

-That portion of the polluted air mass above the nocturnal inversion not subject to the high transport within the jet, serves as an ozone reservoir aloft and fumigates to the surface on the following day, impacting areas not too distant from Sacramento.

4.4 Test 4 23-24 August 1980, Vallejo Release (1500-1700 PDT)

4.4.1 Meteorology

General

The surface and 500 mb synoptic weather charts for 23 August at 0500 PDT are shown in Figure 4.4.1. Synoptic conditions were dominated by a vigorous short wave trough aloft positioned over the western U.S., accompanied by a closed low situated over Northern California. These conditions were reflected in the temperature drop to 17.0° C at 850 mb as depicted on Figure 2.4.3. A period of recovery began on the following day. At the surface, the major 0500 PDT map features were the prior passage of a weak front through Northern California now located in southern Nevada, and the absence of the thermal trough over the California interior. A weak surface low, reflecting conditions aloft was centered near the north end of the Sacramento Valley which resulted in the strongest north-south pressure gradient observed during testing (Table 2.4.2). The onshore gradient remained below the average during the test. Cloudy conditions prevailed in the Valley with overcast skies in the southern half. Virga was observed during aircraft sampling in the Carquinez Straits-Sacramento region. The extensive cloudiness kept surface temperatures well below the August norms with maximum readings of 82° F at Sacramento Executive Airport and 90° at Red Bluff.

Mixing Heights and Vertical Stability

Temperature profiles for 23 and 24 August obtained from airsondes at Sacramento are shown in Figures 4.4.2 and 4.4.3, respectively. From this data it can be seen that the 850 mb (1500 m) temperature remained low on the evening of 23 August and on the following morning. By 1200 PDT on 24 August, a slow warming and stabilizing trend was established. Assuming mixing due only to thermal buoyancy, the mixing height on the 23rd would be about 750 m. However, the warming evidenced below 900 m on the 2000 PDT observation suggests mechanically induced turbulence may have extended mixing through a deeper layer. By 2000 PDT, the nocturnal inversion was developing and in subsequent soundings can be seen to increase to 8°C, cooling a layer 700 m deep.

Mixing heights determined from the 23 August aircraft sampling in the delta and Sacramento areas are shown in Table 4.4.1 below. Southwest of

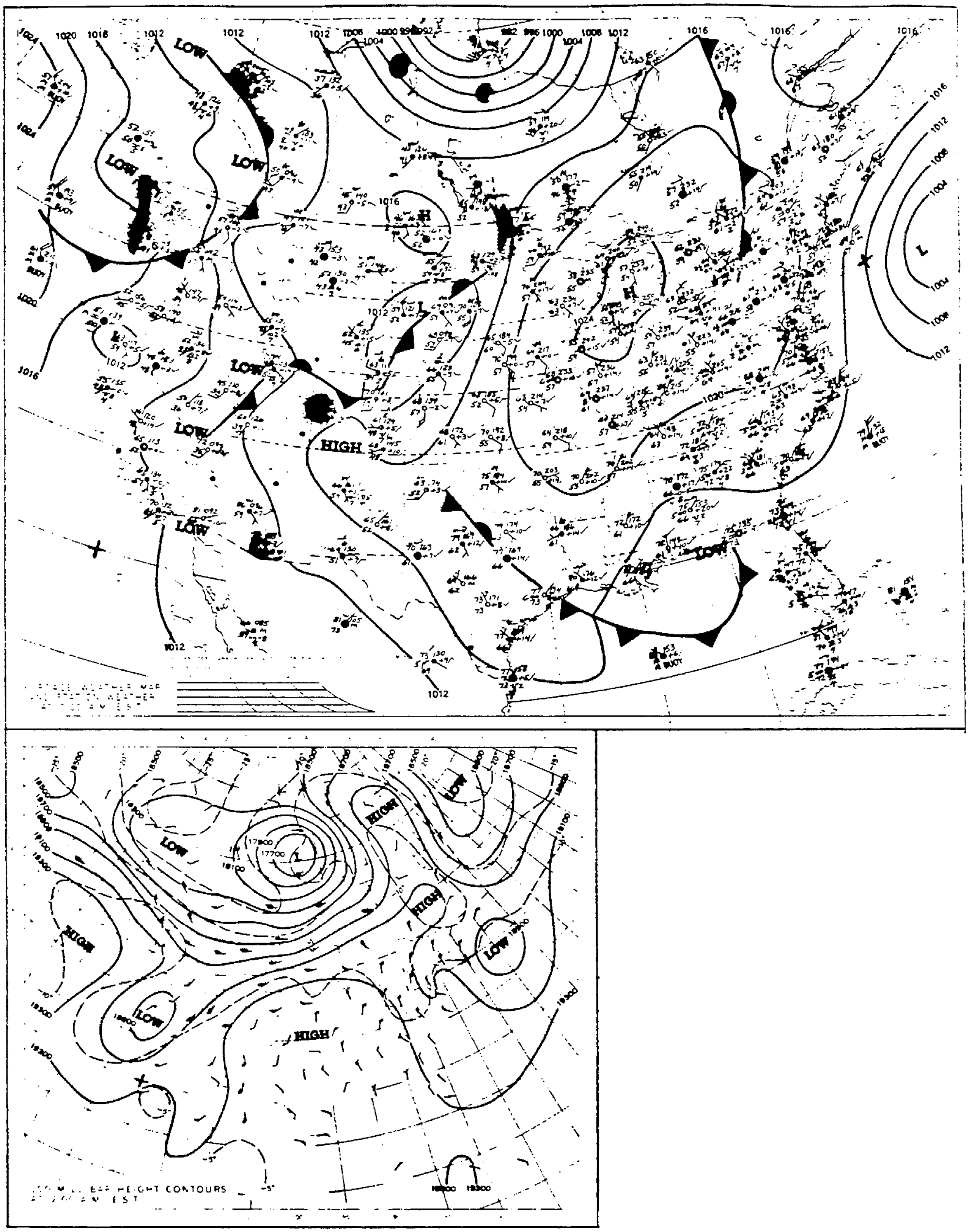
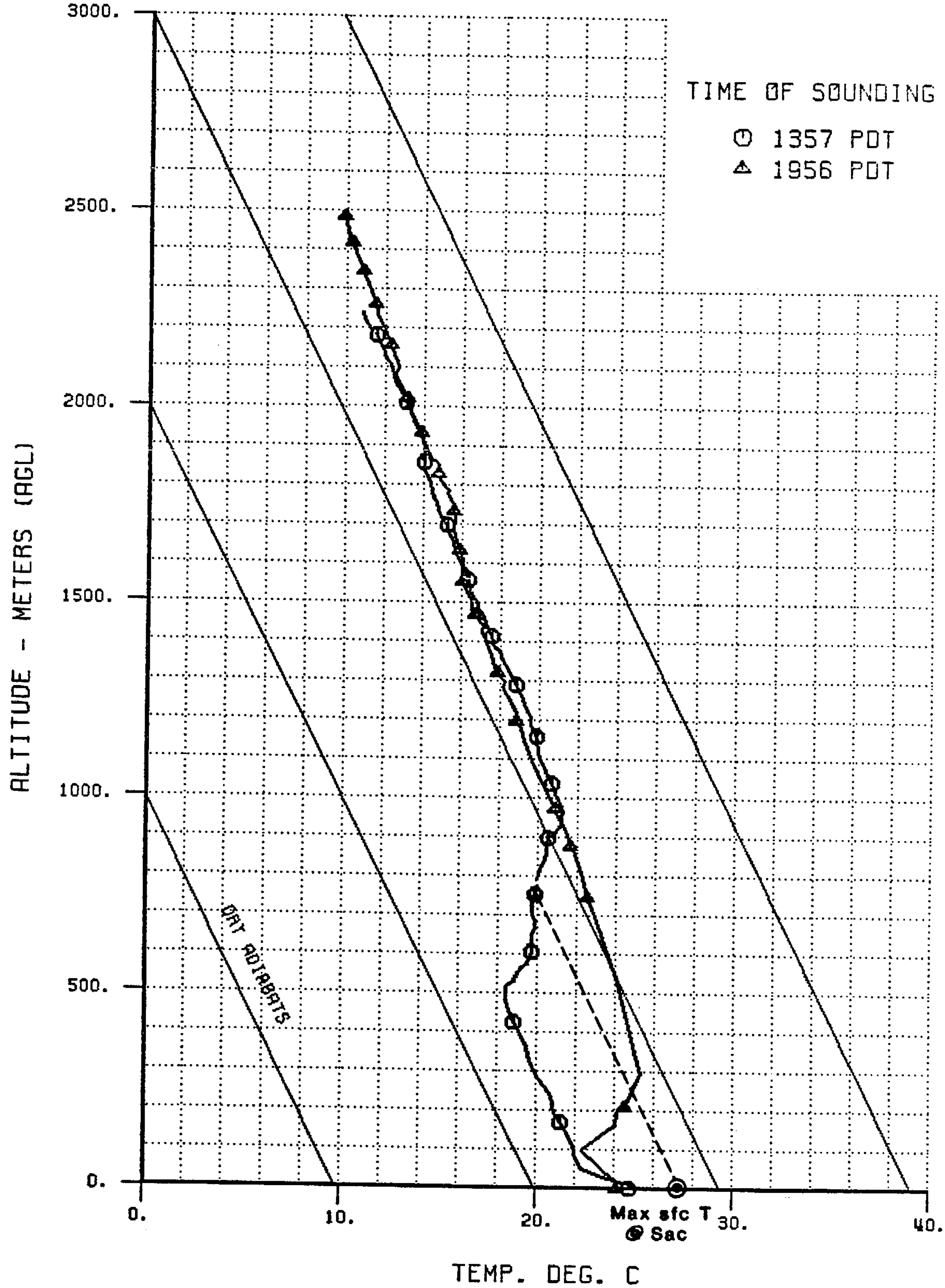


Figure 4.4.1 Surface and 500 mb Weather Charts - 23 August 1980 (0500 PDT)



LOCATION: SACRAMENTO
DATE: 8/23/80

Figure 4.4.2 Temperature Profiles. Dashed line is potential temperature based on maximum surface temperature.

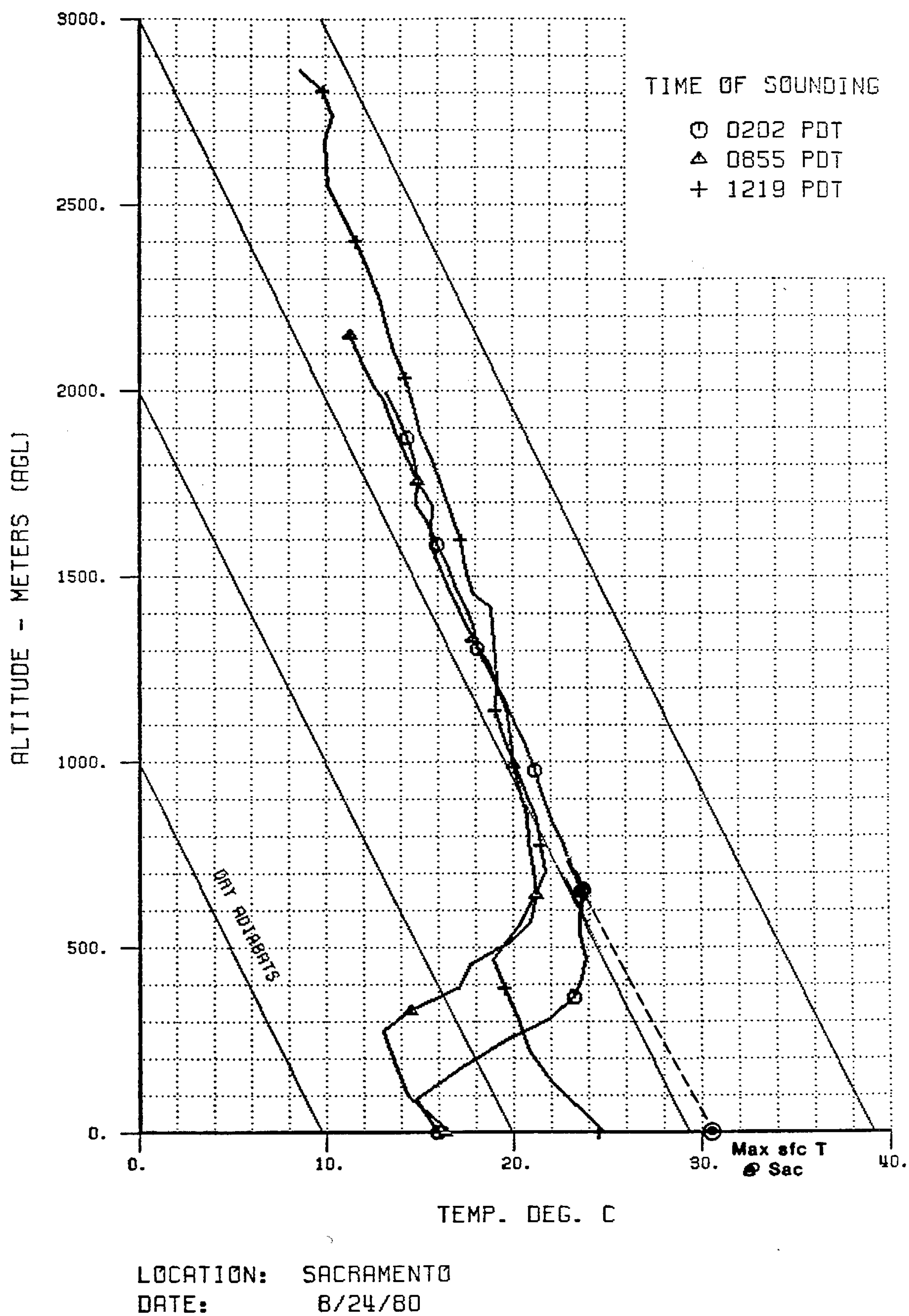


Figure 4.4.3 Temperature Profiles. Dashed line is potential temperature based on maximum surface temperature.

Table 4.4.1

Aircraft Mixing Height
23 August 1980

Time(PDT)	Location*	Mixing Height(m-agl)
1715	5 SW Sac Exec Airport	550
1800	Vacaville (30 SW Sac Exec)	400(1200)
1856	25S Sac Exec Airport	250

*Distance measured in miles

Table 4.4.2

Surface Winds at Vallejo Overlook
23 August 1980

Time(PDT)	Wind(m/s)
1500	200/6.3
1600	210/6.7
1700	210/6.7
1800	205/5.8
1900	215/5.8

Sacramento, mixing was very clearly limited by a 2^{o} C inversion at 550 m. Near Vacaville, a weak (<$.5^{o}$ C) inversion was based at 400 m but turbulence showed non-uniform mixing to about 1200 m. South of Sacramento a deep stable layer was based at 250 m. Due to the late time of sampling there, turbulence was measured only near the ground. Pollutant profiles gave no clear indication of the afternoon mixing height.

Transport Winds

Surface winds at the tracer release location during the release and for a short time thereafter are given in Table 4.4.2. The data in the table show the winds to be from the southwest at approximately 6 m/s during and following the release. The winds aloft at that location (not shown) showed good transport northeast, with velocities ranging from 4-10 m/s.

The vertical time section of the pibal winds at Fairfield, directly 22 km downwind of the tracer release, is shown in Figure 4.4.4. The portion of the tracer plume passing over the Fairfield region from 16-1800 PDT would be directed towards the Sacramento Valley at transport speeds ranging from 6-9 m/s. After 1800 PDT, the wind shear at 150 m would result in transport aloft to be directed somewhat south of east towards Lodi while below 150 m transport would continue to the northeast.

The afternoon and nighttime winds aloft at Sacramento are depicted in Figure 4.4.5. A strong upvalley (southerly) component to the wind was observed at low levels throughout the period. Assuming an average transport speed of 7 m/s from the release site to Sacramento, the tracer plume would first reach the Sacramento area about 1800 PDT. From 1800-2000 PDT, winds at Sacramento were southwest below 350 m at 4-6 m/s. Above 350 m the winds were easterly. The Sacramento winds showed development of a weak nocturnal jet in the Valley during the night. Maximum jet velocities reached 8 m/s at 0200 PDT.

The winds aloft at Rio Vista, located in the Delta some 45 km east of the tracer release location, are shown in Figure 4.4.6. Strong (7-14 m/s) westerly flow persisted at low levels during the late afternoon and evening of 23 August and continued throughout the early morning of 24 August. A persistent westerly flow at mid-levels was observed during the afternoon and evening the previous day. However, coincident with the development of the jet-like low level westerly flow after midnight on the 23 August was the veering of the winds above 800 m; developing an easterly component by

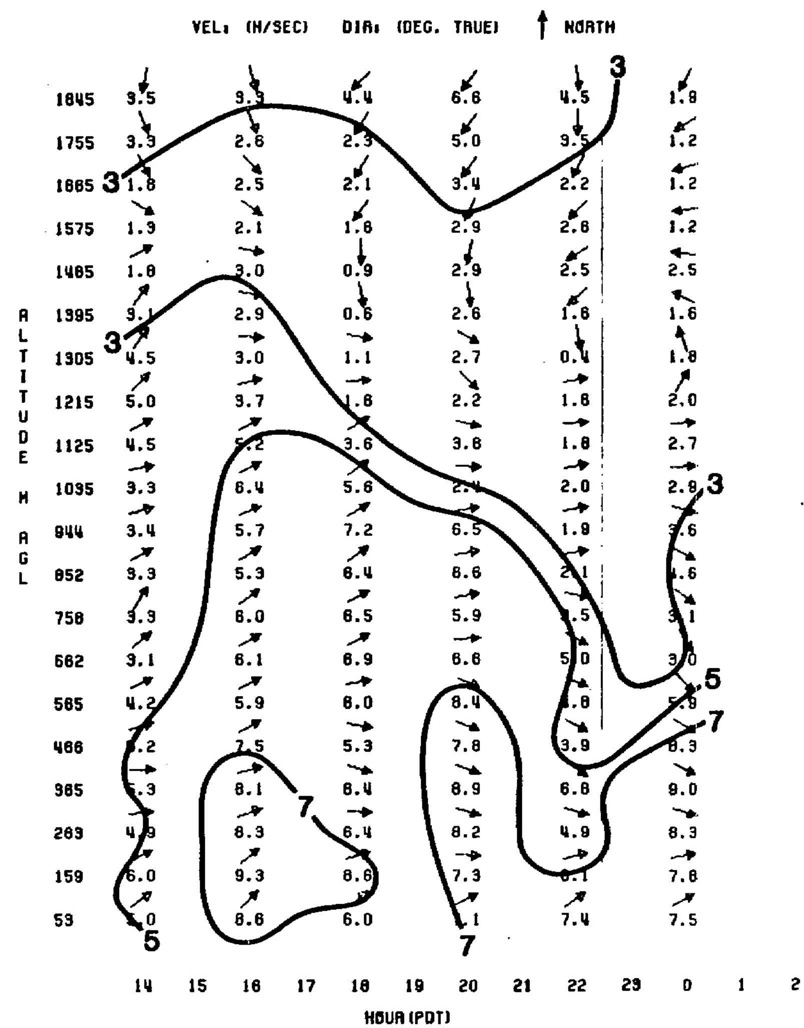


Figure 4.4.4 Vertical Time Section of Winds Aloft at Fairfield. 23-24 August 1980. Wind Speed in m/s.

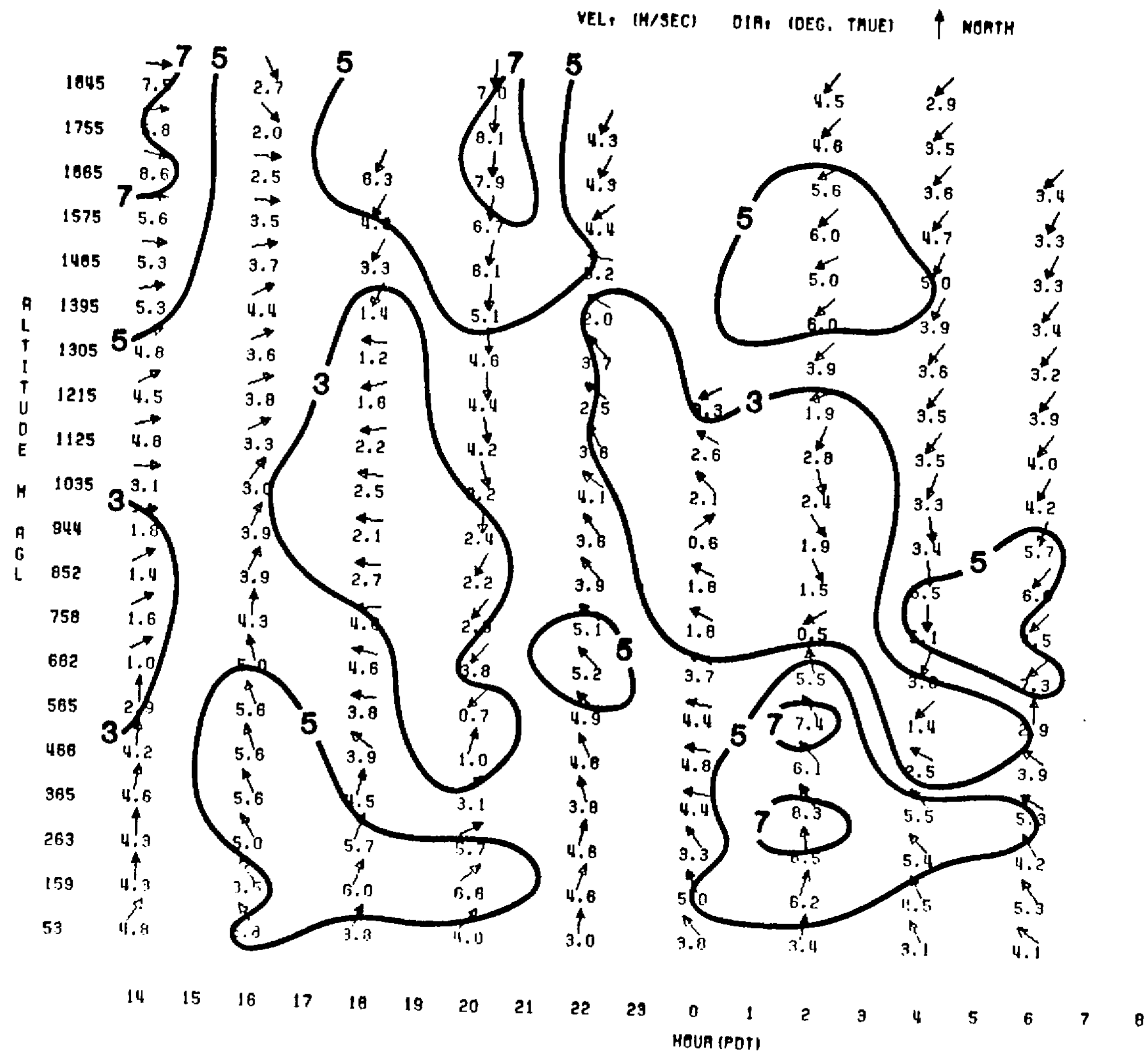


Figure 4.4.5 Vertical Time Section of Winds Aloft at Sacramento (Downtown) on 23-24 August 1980. Wind Speed in m/s.

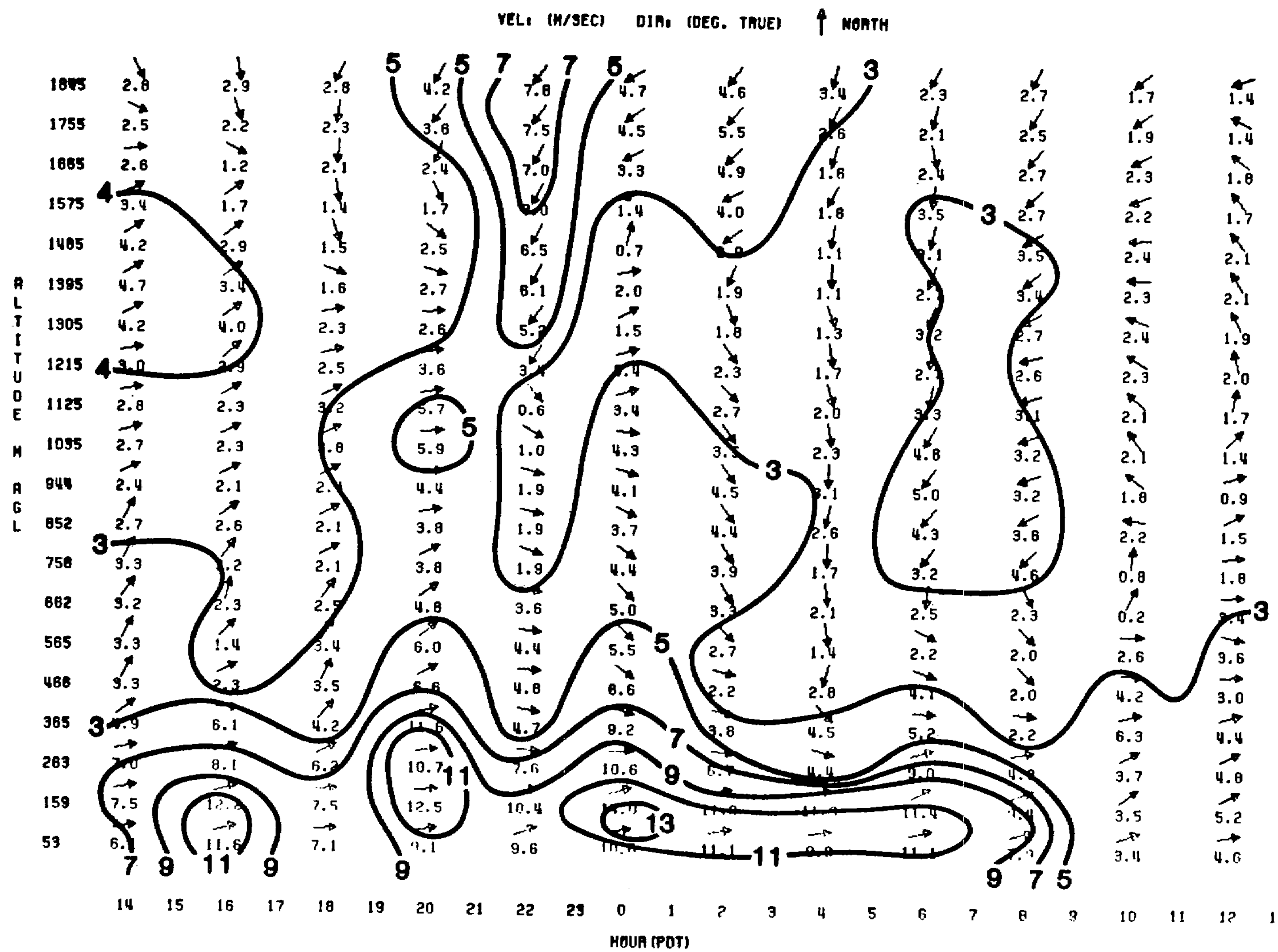


Figure 4.4.6 Vertical Time Section of Winds Aloft at Rio Vista on 23-24 August 1980. Wind Speed in m/s.

daybreak. By 1200 PDT that morning, the flow had again become westerly. This may be another ventilating mechanism for the Central Valley if it is related to the zone of relatively high ozone levels observed moving west aloft over the straits during the 9 August experiment.

4.4.2 Air Quality

Aircraft Sampling

Aircraft sampling was conducted from 1715-2010 PDT on the afternoon of 23 August. The sampling route is depicted on Figure 4.4.7. As shown in the figure, sampling was concentrated southwest of Sacramento and near the boundary between the Carquinez Straits and the Central Valley. Spirals were flown over the Nut Tree Airport(Pt. 2) and south of Sacramento. Along the transect west to south of Sacramento (Points 5-1-4), the airplane sampled at two altitudes; one within the mixing layer and the other within the stable layer aloft.

Table 4.4.3 is a summary of the measurements on each segment of the afternoon sampling flight. From the table it is seen that generally good air quality was experienced. The only ozone value in excess of 10 pphm was in a layer aloft between 2300-2500 m southwest of Sacramento (Pass 1). Maximum b_{scat} levels measured during this sampling flight were within the same layer. Maximum NO_x concentrations on the order of 2 pphm were found at the surface near I-80 and within the mixing layer near Brentwood.

Temperature-ozone profiles are shown in Figure 4.4.8 for the three spirals. The temperature profiles all show dissimilar stability and inversion characteristics in the lower 500 m. On the other hand, above 500 m the soundings all show a distinct stable layer. And in all cases, maximum ozone concentrations were experienced above the surface mixing layer. Ozone scavenging near the ground is apparent over Points 2 and 4, reflecting the stable conditions in the lower 200 m. Ozone averaged about 8 pphm within the mixing layer at Point 1.

Plots of the various air quality parameters measured on the traverse from Point 2 to Point 3 across the zone where the flow through the Carquinez Straits diverges into the Central Valley are shown on Figures 4.4.9 and 4.4.10. From Figure 4.4.9 it is seen that a diffuse NO_x plume was intersected at the southern end of the traverse beginning about 20 km from Brentwood. Otherwise NO_x concentrations were below detection. The

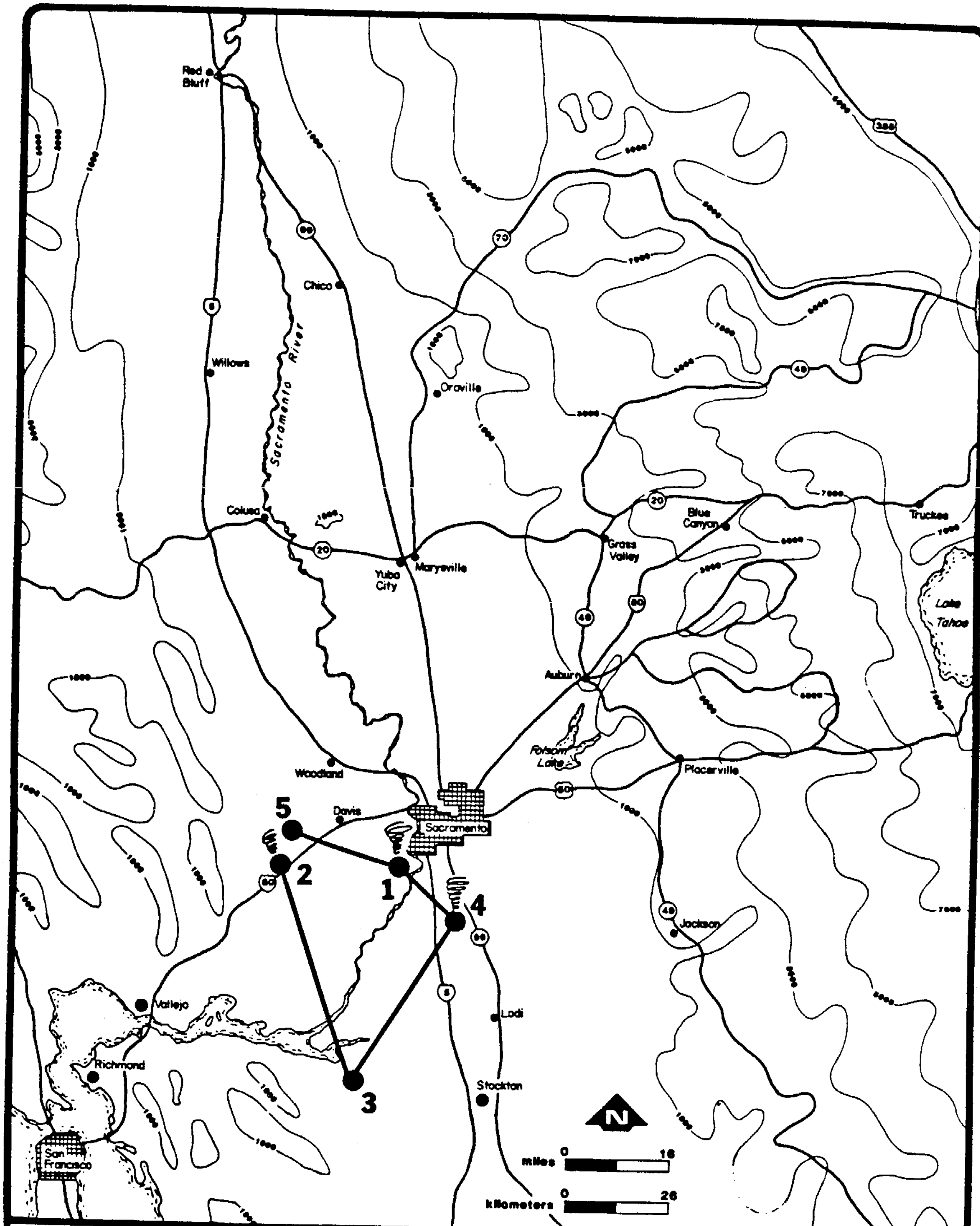


Figure 4.4.7
Sacramento Valley Oxidant Study
MRI 206 Sampling Flight Map

TEST 4 23 August 1980 Tape #153

Table 4.4.3

AIR QUALITY MEASUREMENTS CARB SACRAMENTO VALLEY PROJECT
AUGUST 23, 1980 SAMPLING

Start Time (PDT)	Location (Point)	Altitude (m-msl)	O_3 Mean (ppb)	O_3 Max (ppb)	b_{scat} Mean ($\times 10^{-6} m^{-1}$)	b_{scat} Max ($\times 10^{-6} m^{-1}$)	NO_x Mean (ppb)	NO_x Max (ppb)	NO Mean (ppb)	NO Max (ppb)	SO_2 Mean (ppb)	SO_2 Max (ppb)
1715	1	11-2743	81	106	113	301	6	14	3	7	2	9
1800	2	2743-55	61	79	95	160	3	26	2	9	1	9
1824	2-3	305	53	75	82	147	6	22	3	7	1	2
1843	3-4	305	53	67	80	129	8	16	3	6	1	2
1856	4	8-1829	74	94	96	156	5	14	3	6	1	3
1933	1-5	305	74	83	98	140	7	18	2	6	2	5
1949	5-1	762	76	89	103	231	5	10	2	5	1	2
2002	1-4	762	66	85	82	142	5	11	1	5	1	3
2010	4-1	305	69	82	74	113	4	9	1	5	2	3

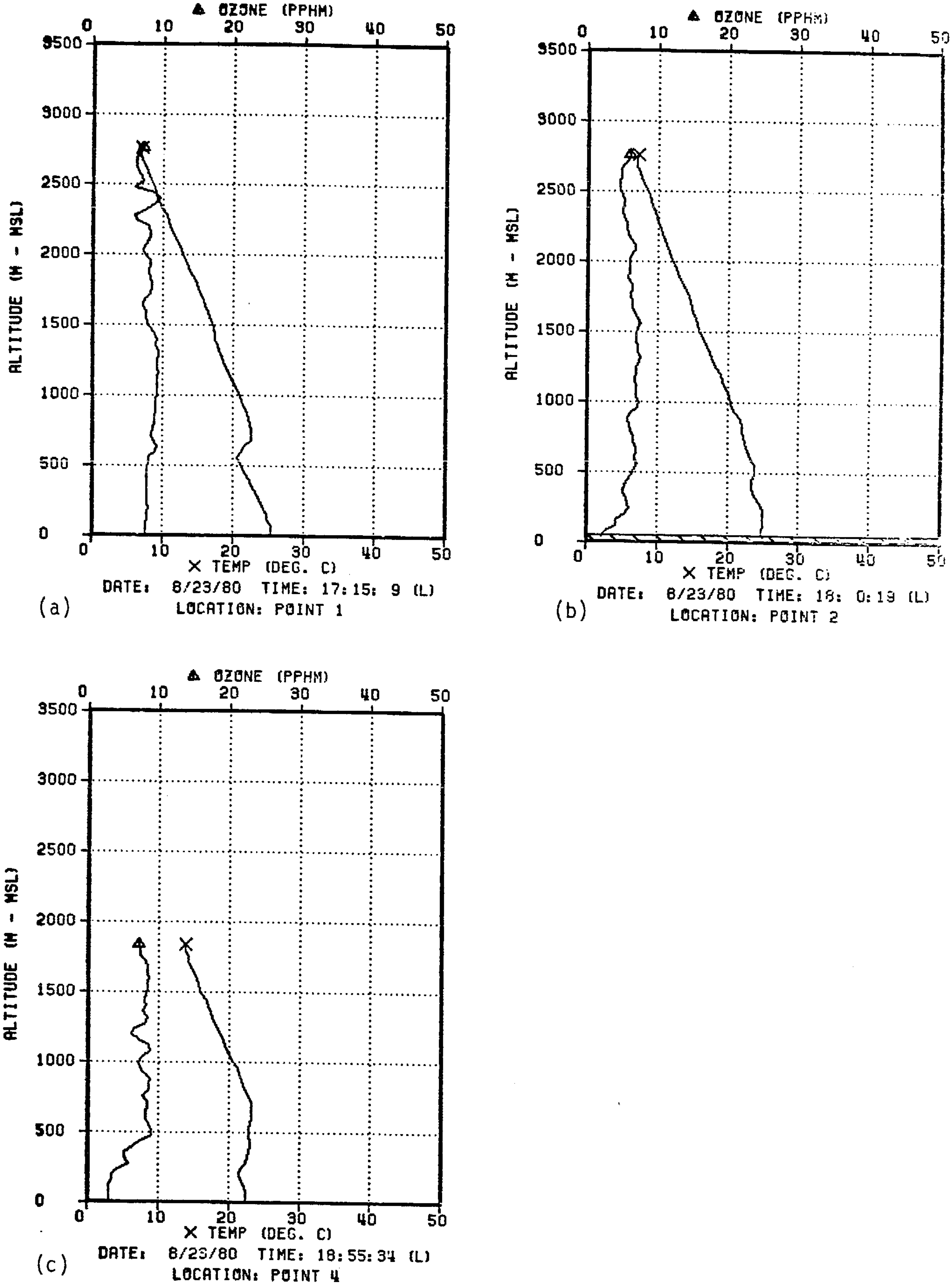


Figure 4.4.8 Temperature-Ozone Profiles Over a) 5 mi SW Sac Exec AP, b) Nut Tree AP (Vacaville), and c) 25 mi S Sacramento.

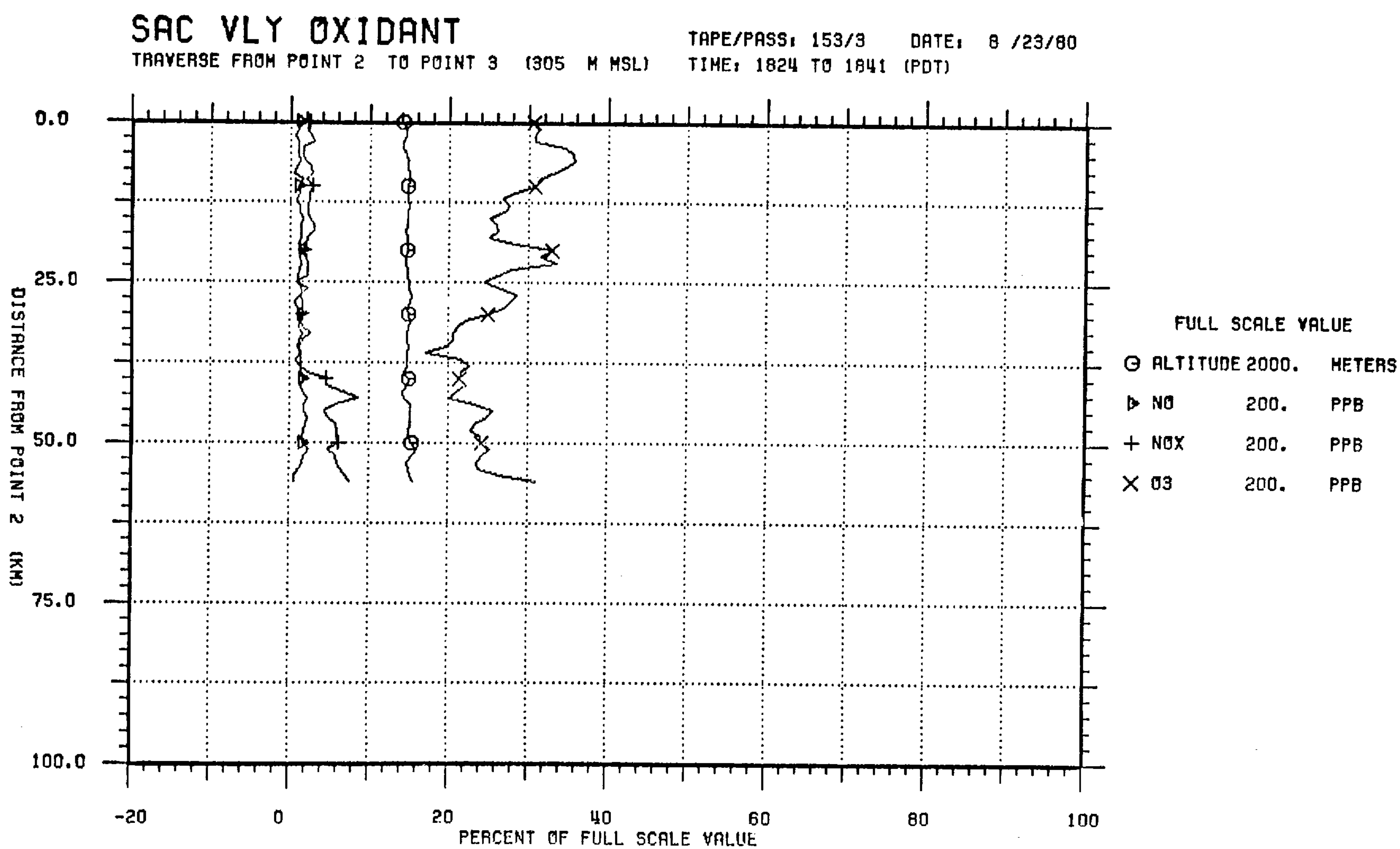


Figure 4.4.9 Airplane Traverse from Vacaville to Brentwood, 305 m-msl. 23 August 1980. Showing NO, NO_x, O_3.

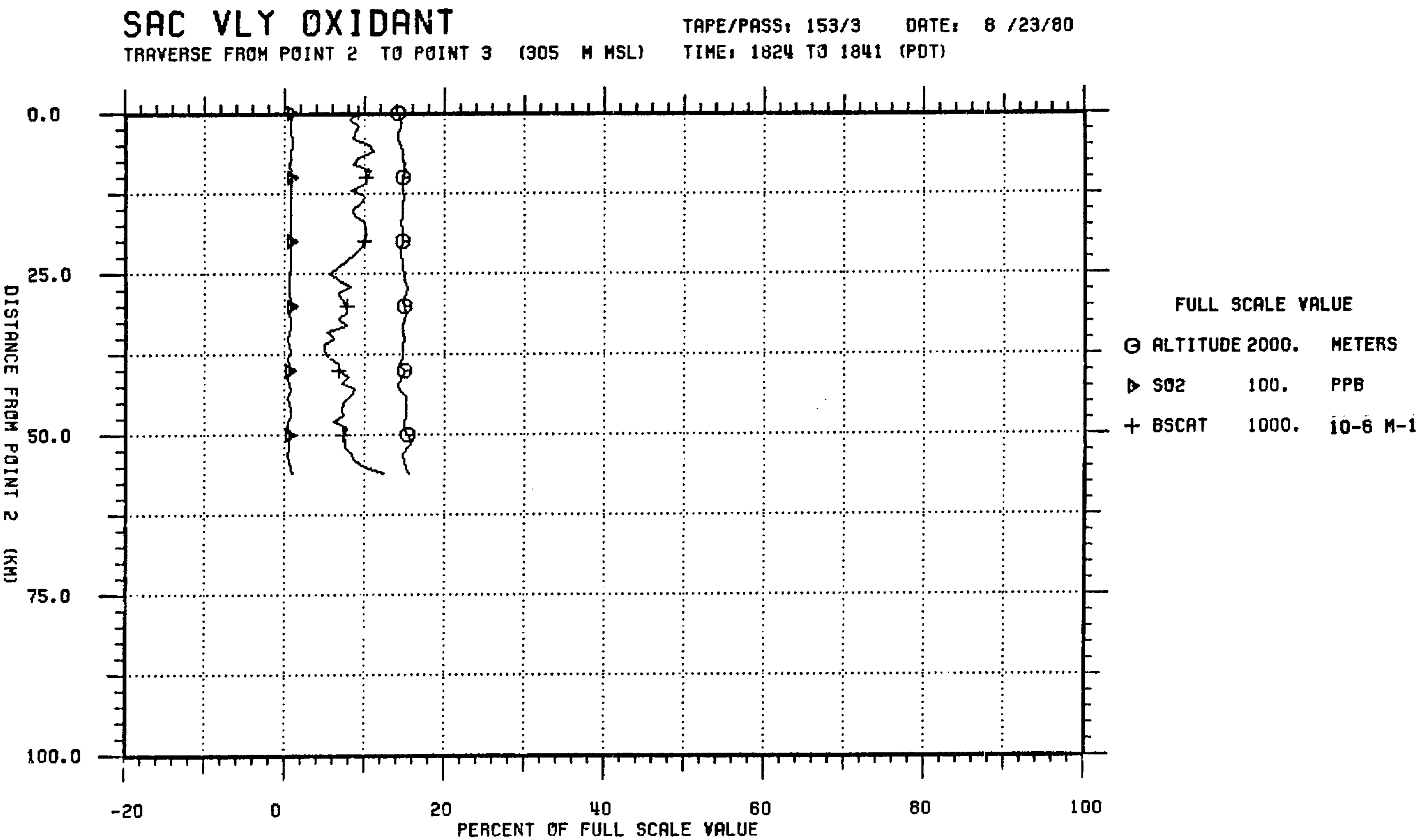


Figure 4.4.10 Airplane Traverse from Vacaville to Brentwood, 305 m-msl. 23 August 1980. Showing SO_2 and b_{scat}.

distribution of ozone was extremely non-uniform as it was throughout the sampling. Ozone generally, however, shows a minimum in the NO_x plume. As shown in Figure 4.4.10, levels of particulate loading and SO_2 were very low.

Figure 4.4.11 reveals a strong highway traffic plume along the 305 m altitude traverse from Point 1 to Point 5 crossing I-80. The distributions of ozone and nitrogen oxides are shown therein. Ozone, averaging 7-8 pphm ambient levels, dropped to less than 5 pphm near the centerline of the NO_x plume.

Regional Surface Oxidant Levels

Hourly averaged surface ozone concentrations for selected locations within the study area are shown in Figure 4.4.12. No exceedance of the State Standard for oxidant was experienced although Auburn, Sutter Buttes and Redding all showed instances of 9 pphm levels. Ozone concentrations reached maximum concentrations between 13-15 PDT at all locations. At Redding, levels remained 8-9 pphm for 8 hours although wind speeds there were in excess of 5 m/s for much of the period. Redding's southerly winds with those speeds indicate similar ozone concentrations were widespread in the Valley.

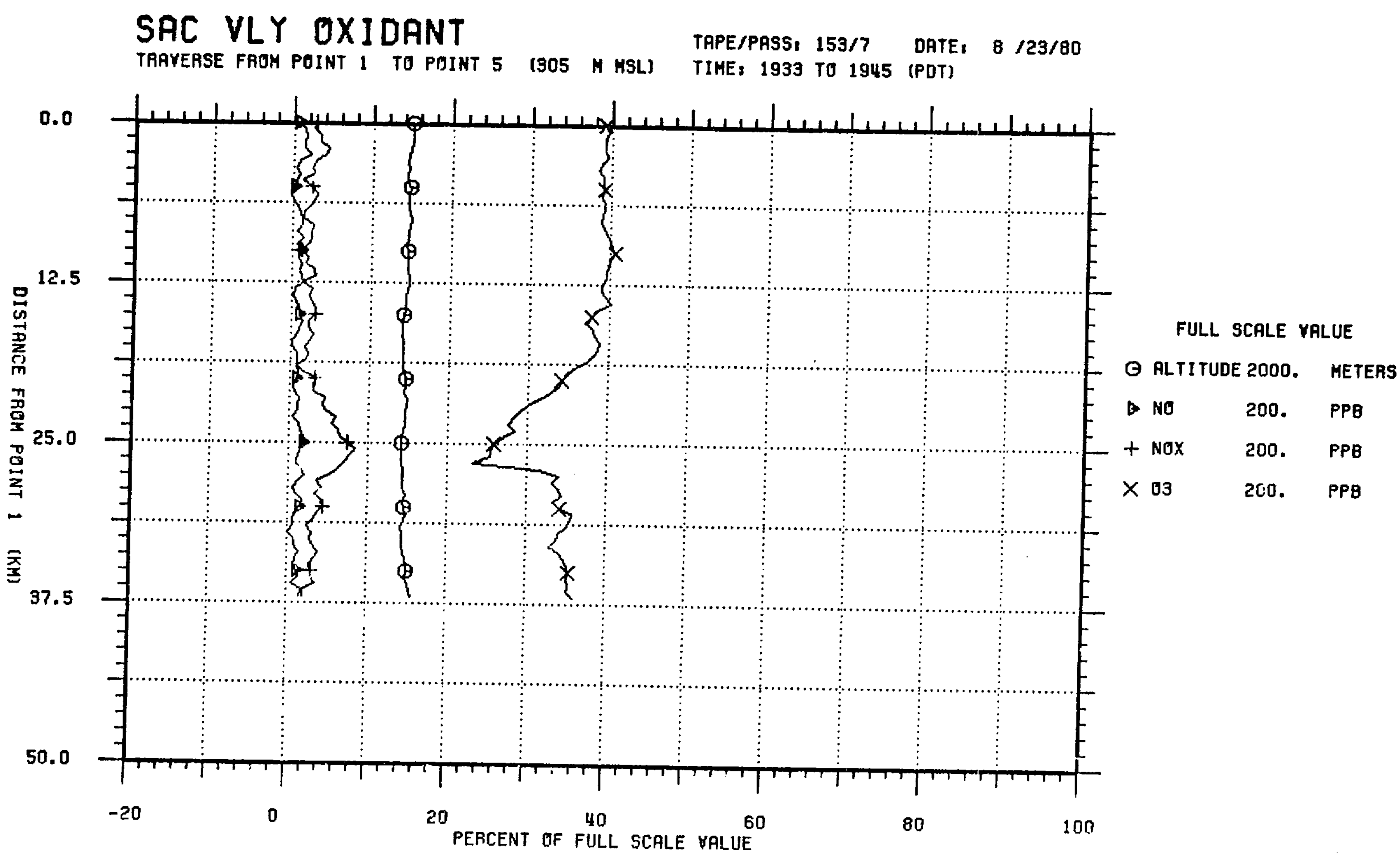


Figure 4.4.11 Airplane Traverse from 5 mi SW Sacramento Executive AP to Winters, 305 m-msl. 23 August 1980. Showing NO, NO_x, O_3.

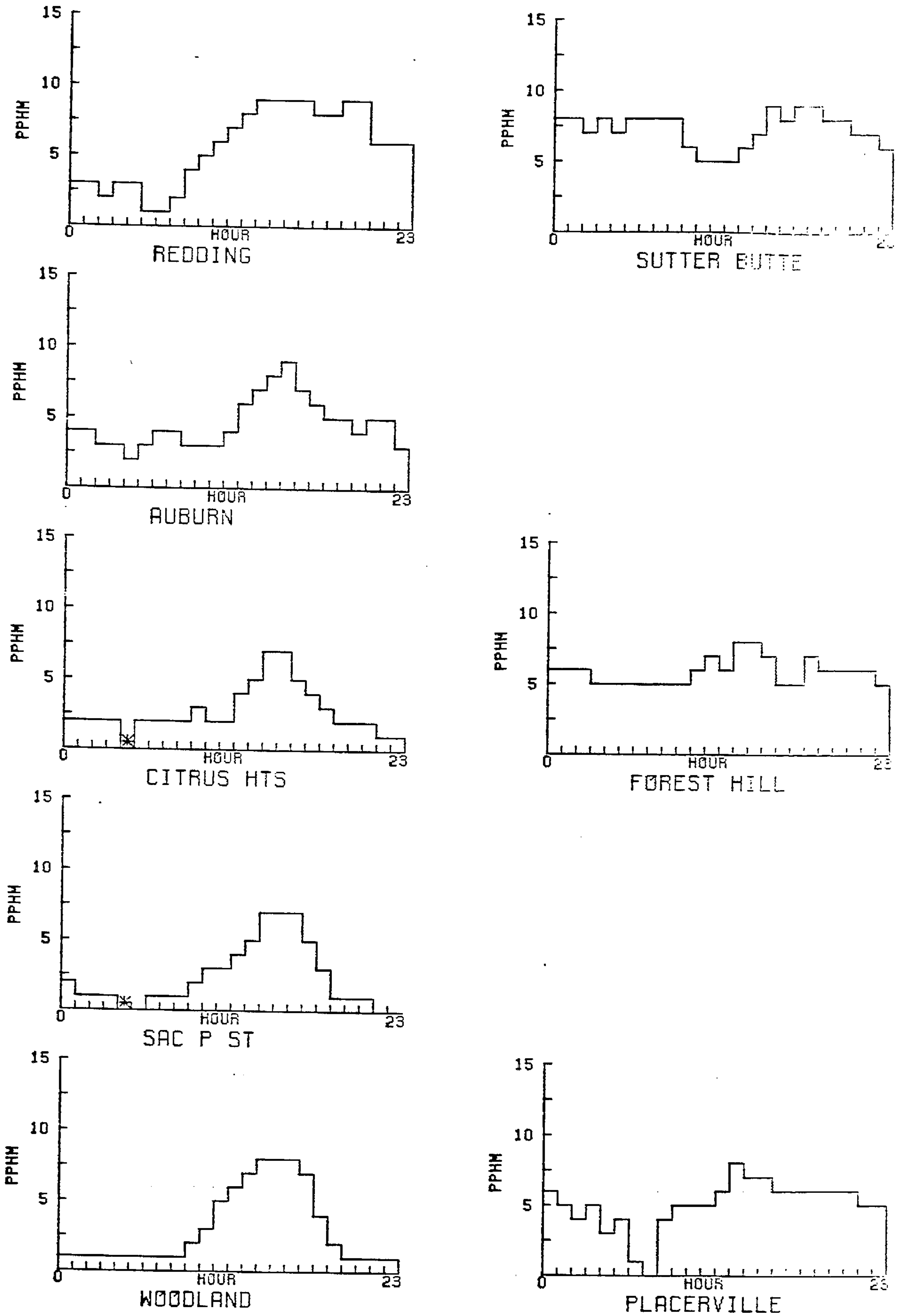


Figure 4.4.12 Hourly Averaged Oxidant Concentrations at Selected Locations. 23 August 1980 (* indicates missing data)

4.4.3 Tracer Results

About 400 lbs of SF_6 were released from an I-80 rest area overlooking Vallejo between 1500 and 1900 PDT on 8/23/80. This site was also used during the first tracer study. The tracer was transported towards the northeast and the intersection of I-80 and I-680 and finally towards the north of the Fairfield area. Approximately 3-1/2 hours after the beginning of the release, SF_6 was detected in Sacramento at concentrations approaching 200 PPT.

The major tracer transport, as shown by the hourly concentrations in Figure 4.4.13, was northward into the Sacramento Valley. The estimated trajectories of the SF_6 plume are given in Figure 4.4.14. The major plume was carried northeastward initially along Highway I-80 to an area south and east of Marysville. By 2200-0000 PDT the wind shifted direction from southwesterly to southerly or southeasterly (Figure 4.4.5). The plume which had been extended in a northeast-southwest orientation then apparently moved toward the northwest, covering a wide area of the Valley. Strong peaks were observed at Colusa, Williams, Marysville, Oroville and Chico.

Auto traverses on the following morning showed widespread, rather uniform SF_6 concentrations in an area from Red Bluff to Oroville to Williams. This represented significant evidence of extensive carry over in the Valley for pollutants entering from the Bay area.

A secondary and distinct plume (Figure 4.4.14) passed slightly to the south of Sacramento and probably was carried northward and northeastward with the late evening wind shift.

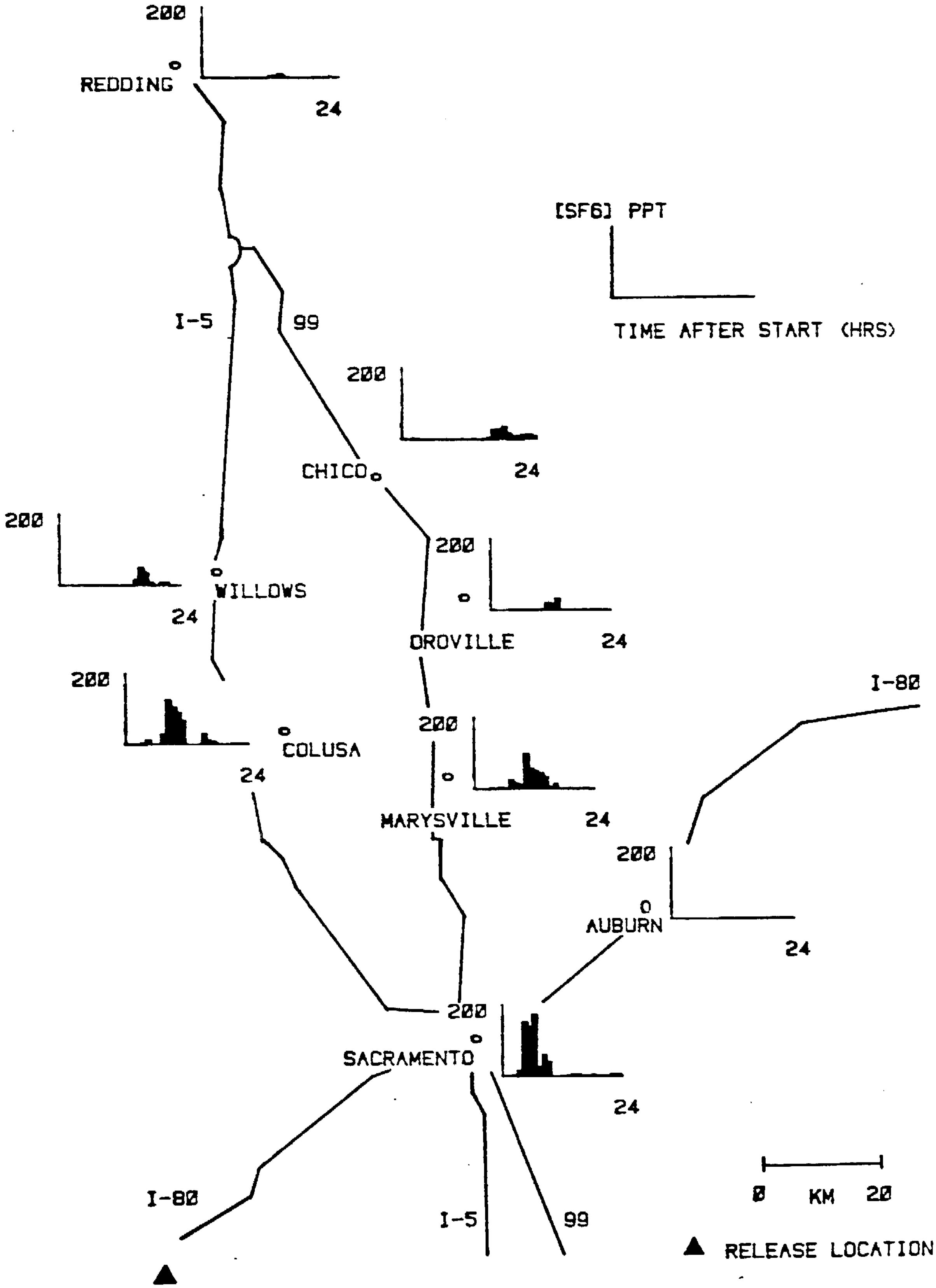


Figure 4.4.13 Hourly Average SF_6 Concentrations
Test 4 - August 23, 1980

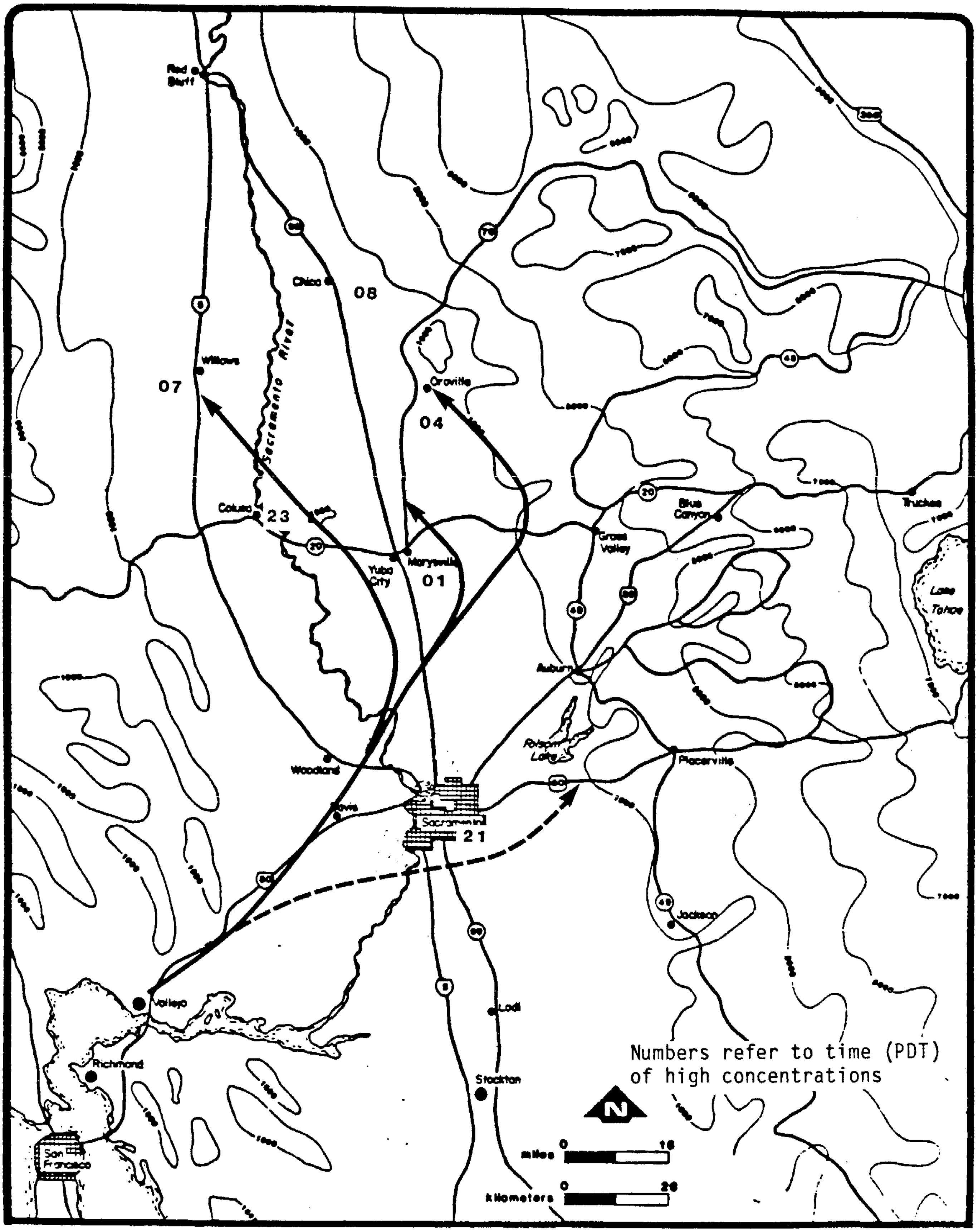


Figure 4.4.14 Tracer Trajectories - Test 4
August 23, 1980 - 1500-1900 PDT

4.5 Test 5 25-26 August 1980, Downtown Sacramento Release (0700-1100 PDT)

4.5.1 Meteorology

General

The synoptic meteorology of the test period is depicted by the weather charts on Figure 4.5.1. Conditions in the Valley were beginning to stabilize as a low pressure system aloft, which had been adversely affecting Northern California for the previous few days, moved eastward. As reflected in the 850 mb temperature trend plotted in Figure 2.4.2, this period can be characterized as only a brief stabilizing and warming trend between the continuing series of cold air intrusions aloft with temperatures remaining below the long-term average. At the surface, although the Pacific High was reestablishing itself in a typical seasonal configuration, the thermal trough had not yet redeveloped over the interior of California. These conditions are reflected in the local pressure gradients shown in Table 2.4.2. Both the east-west and north-south gradients, although favorable for upvalley flow, were below the average.

Visibilities were generally good to excellent in the Valley, ranging from 7 mi in the morning to 20 mi in the afternoon at Sacramento to over 60 mi at Redding. Skies were clear over the Valley with cumulus reported over the mountains. Surface temperatures remained below the normal for August with Sacramento reporting a high of 87°F and Redding 90°F.

Mixing Heights and Atmospheric Stability

The temperature soundings at Sacramento for 25 August are shown on Figure 4.5.2. From the figure it is seen that the test began under an 11°C inversion, based at 200 m and extending to 650 m. From the maximum surface temperature reported at Sacramento, mixing due to thermal convection would be expected to reach 500-600 m during the afternoon. Warming aloft and stabilization is evidenced by the increase in temperature at the 850 mb level (1500 m) from 18° in the morning to 20° by afternoon.

As can be seen from Table 4.5.1, aircraft sampling measured mixing to be restricted below 600 m in the Sacramento area. In the Sierra foothill region, the mixing layer deepened to 1000-1050 m. Morning aircraft soundings were in good agreement with the airsonde temperature data; showing surface mixing to about 200 m.

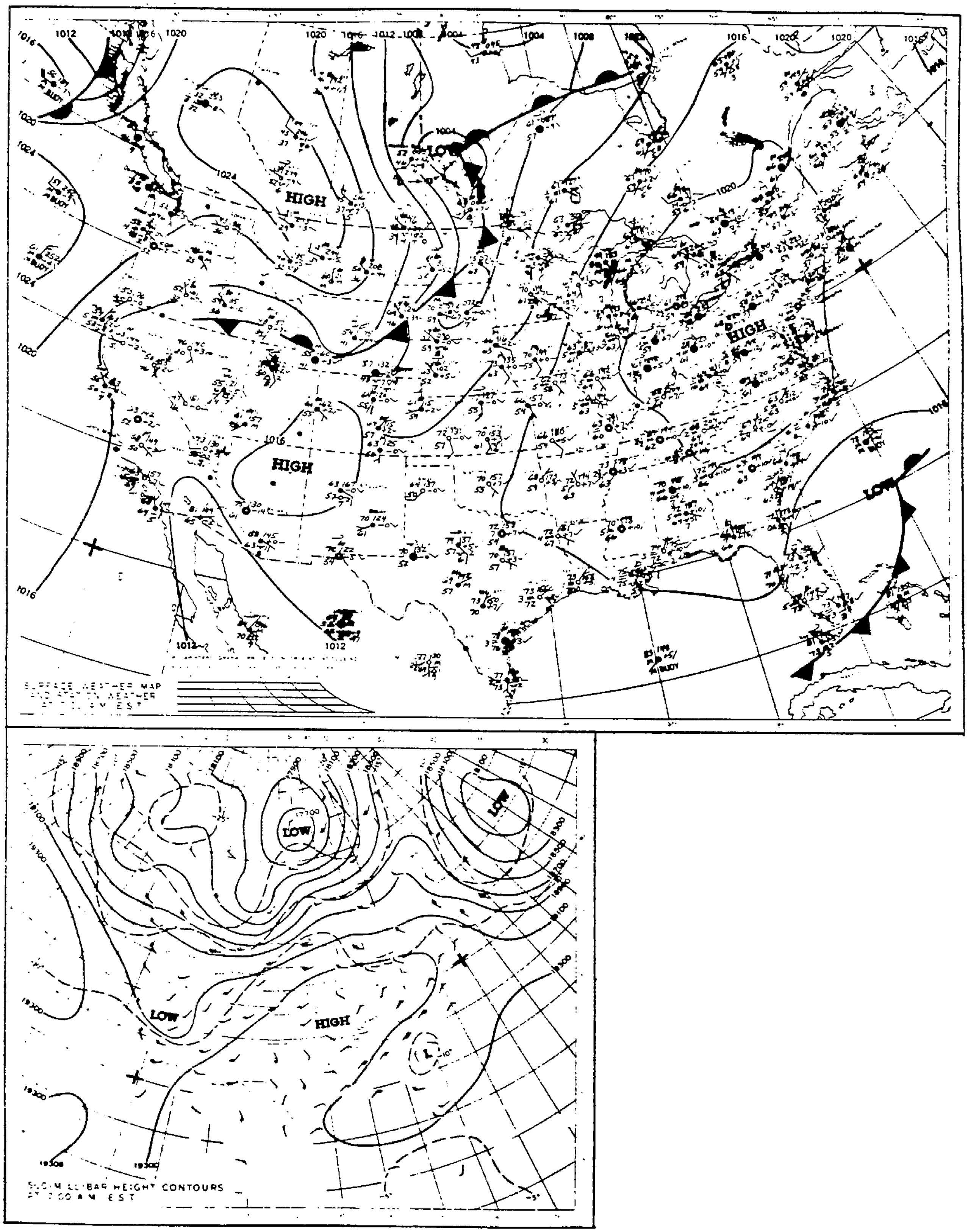


Figure 4.5.1 Surface and 500 mb Weather Charts - 25 August 1980 (0500 PDT)

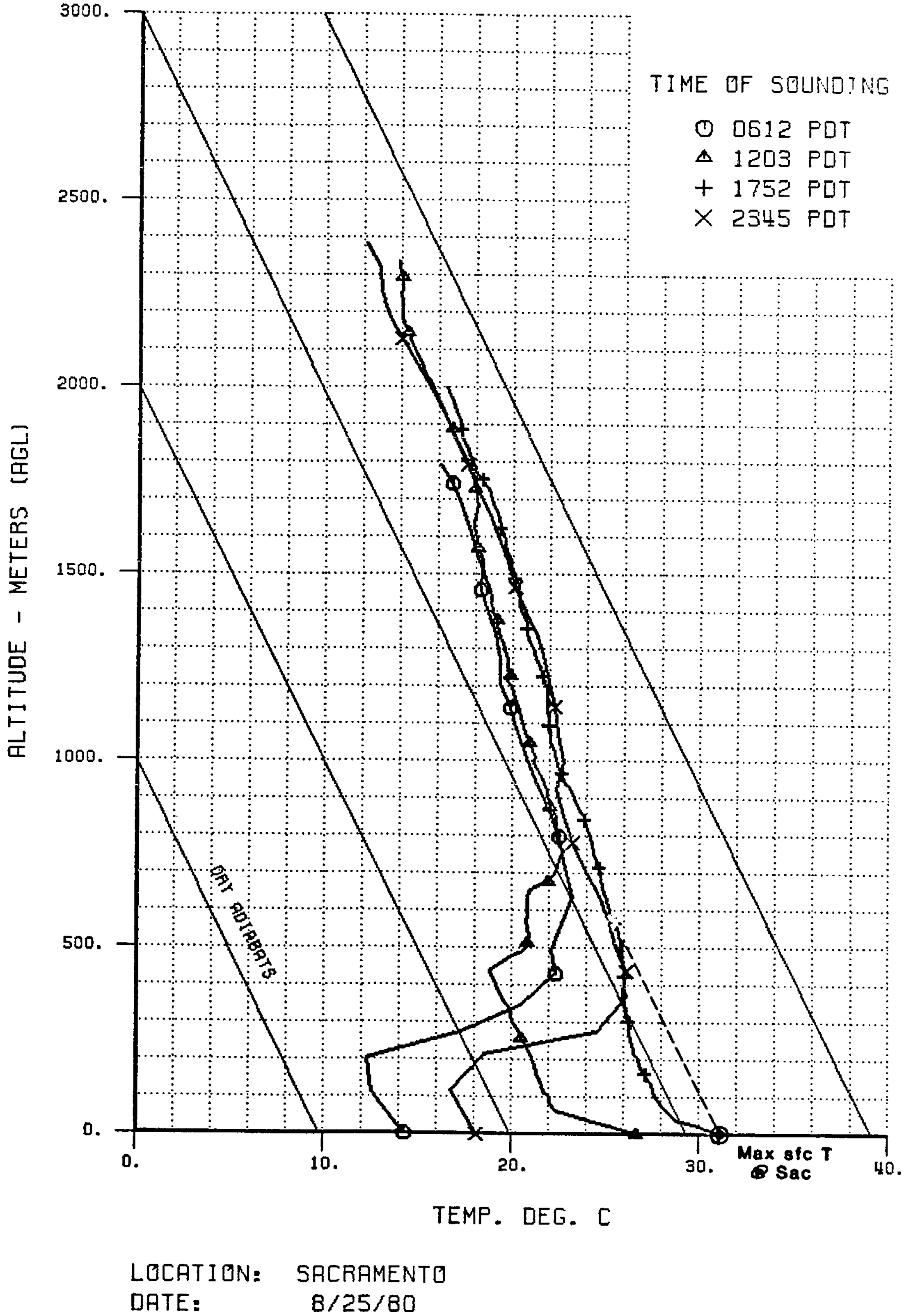


Figure 4.5.2 Temperature Profiles. Dashed line is potential temperature based on maximum surface temperature.

Table 4.5.1

Aircraft Mixing Heights
25 August 1980

Time(PDT)	Location*	Mixing Height(m-agl)
0623	5 SW Sac Exec Airport	200
0653	Rio Linda Airport (10 NW Sac Exec)	200
0715	Phoenix Airport (15 ENE Sac Exec)	150
1351	5 SW Sac Exec Airport	550
1518	W tip of Folsom Lake (Pt. 6)	1050
1545	E tip of Folsom Lake (Pt. 7)	1050
1605	North Fork Dam (Bowman Res) (Pt. 8)	1000
1657	Georgetown Airport (Pt. 11)	1000

*Distance in miles (see Figure 4.5.5)

Transport Winds

As can be seen from the winds at Sacramento listed in Table 4.5.2, the surface flow during the first half of the tracer release was southerly at about 4-5 m/s, becoming southwesterly by 1000 PDT. Throughout the remainder of the day the flow continued from the southwest and west at velocities on the order of 4-6 m/s. The vertical time section of the pibal winds from Sacramento (Figure 4.5.3) show a southerly low level flow at 0600 PDT becoming southwesterly by 0800 PDT. Southwesterly winds, 1-6 m/s, continued within the mixing layer the remainder of the day. Maximum wind velocities within the mixing layer were observed at 1800 PDT when speeds increased to over 11 m/s. Thus early in the release, transport at the surface was north but northwest in the layer from the surface to 200 m (airplane morning mixing depth). After 1000 PDT the winds in the mixing layer were relatively uniform from the southwest. Table 4.5.2 also includes the surface winds at McClellan AFB, some 13 km northeast of the release location. Prior to 1600 PDT, winds there were generally more southerly than at Sacramento Executive Airport and at reduced speeds, ranging from 1.5 - 3 m/s. After 1600 PDT, wind directions at the two locations were similar although McClellan still exhibited lower wind speeds.

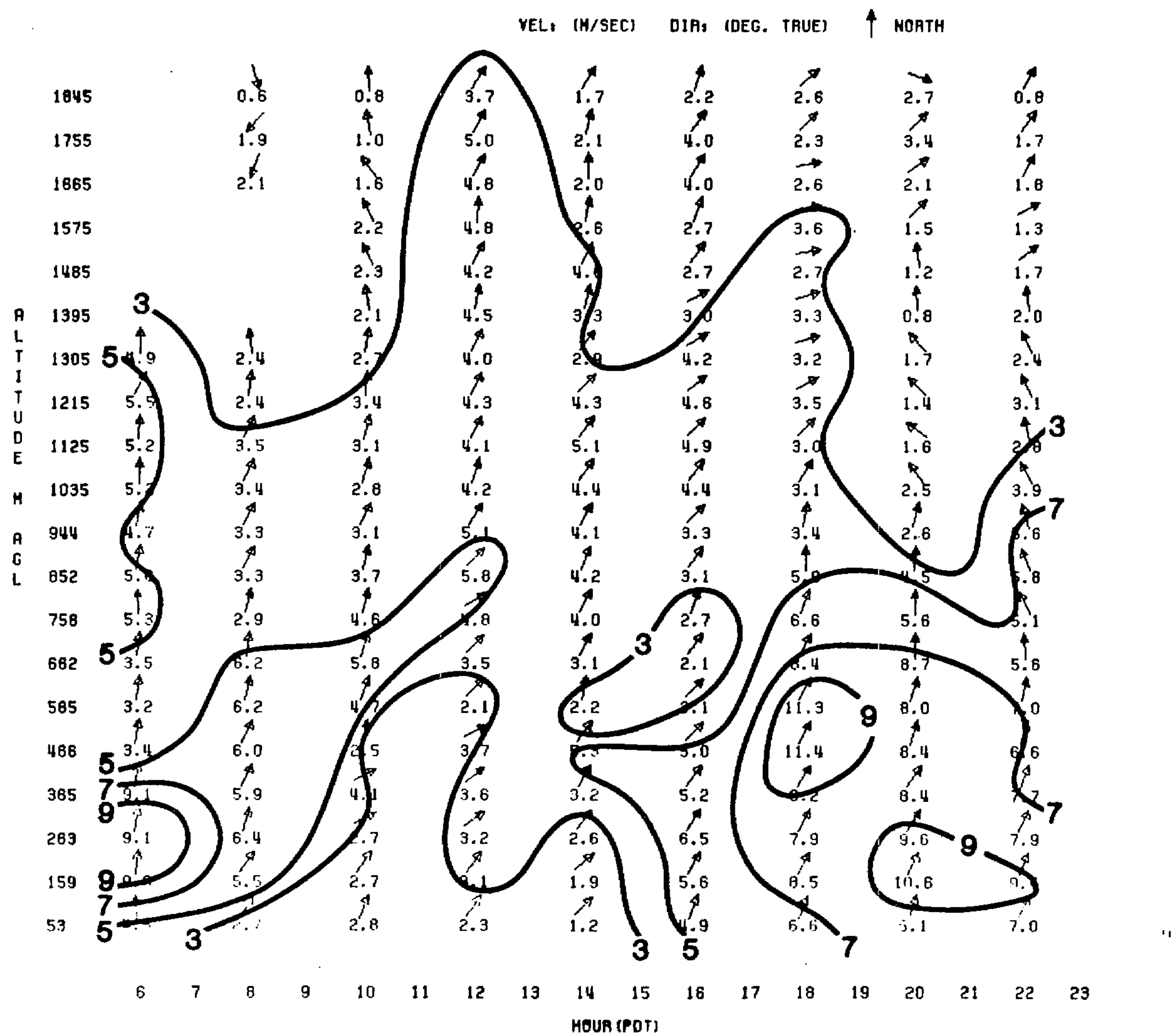


Figure 4.5.3 Vertical Time Section of Winds Aloft at Sacramento (Downtown) on 25 August 1980. Wind Speed in m/s.

Table 4.5.2

Surface Winds(m/s) from Sacramento and the Sierra Foothills

Time	Sac Exec Airport	McClellan AFB	White Cloud
07	170/4.1	170/2.5	060/1.8
08	190/4.6	180/3.1	130/1.6
09	190/4.6	160/2.5	170/2.0
10	210/5.1	210/2.5	230/2.7
11	230/4.1	190/2.5	220/2.9
12	230/4.1	210/2.5	245/3.1
13	250/4.1	200/1.5	235/3.1
14	250/4.1	210/2.5	235/2.9
15	240/4.1	200/3.1	255/2.9
16	200/4.6	230/2.0	220/2.9
17	220/6.1	220/3.6	250/2.2
18	210/6.1	200/4.1	255/1.8
19	190/4.6	190/2.0	270/0.9
20	210/5.1	200/2.5	245/0.2
21	200/5.1	170/3.1	030/0.7

As shown above, mid day and afternoon transport from the Sacramento area was to the northeast. Pibals were taken northeast of Sacramento from two locations, Auburn and White Cloud. White Cloud was also one of the locations of surface meteorological and air quality measurements. The surface winds from White Cloud, in the Sierra foothills, are listed in Table 4.5.2. The data in the table show that by 1000 PDT upslope flow was established at the surface and continued until after 1800 PDT. By 1900 PDT, the flow was less than 1 m/s although still directed upslope. By 2100 PDT a weak drainage flow was beginning to develop. Winds aloft at White Cloud and at Auburn both show similar characteristics. The vertical time section of the pibal winds at Auburn is shown in Figure 4.5.4. Prior to 1200 PDT, the lower level flow was directed either away from or parallel to the mountains. From 1200-1800 PDT, the flow within the mixing layer was directed upslope at speeds generally 2-4 m/s. At 1800 PDT, a southeast flow is evident above 700 m to where the mixing

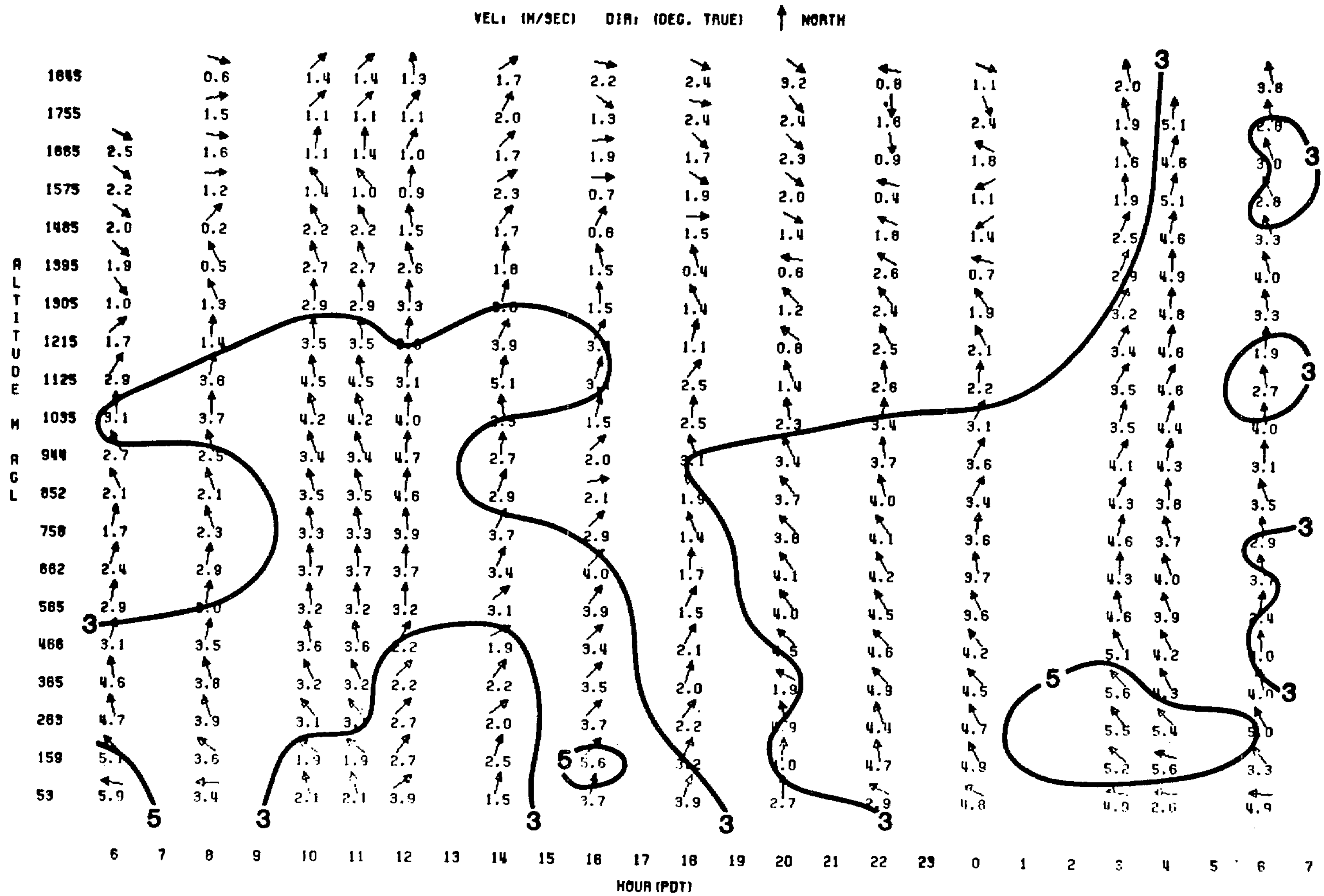


Figure 4.5.4 Vertical Time Section of Winds Aloft at Auburn on 25-26 August 1980. Wind Speed in m/s.

layer had extended earlier, reflecting the decrease in depth of convective mixing as the surface heat flux decreased. By 2000 PDT, the southeast flow had replaced the upslope flow at all but the lowest layers. As noted in previous tests, this implies that urban air from Sacramento which reached the Sierra foothills by late afternoon would be transported upvalley during the night.

4.5.2 Air Quality

Aircraft Sampling

Aircraft sampling was conducted both in the morning and afternoon of 25 August. The morning sampling was discussed in Section 3 and measured fairly typical morning inversion characteristics with low pollutant accumulations within the city. Afternoon sampling consisted of a series of traverses and spirals downwind to the north and northeast of Sacramento. The complete sampling pattern is depicted in Figure 4.5.5. All traverses were flown within the mixing layer. Table 4.5.3 is a summary of the pollutant measurements on each segment of the afternoon sampling flight. The major impact of the Sacramento urban plume was measured northeast of Sacramento in an almost identical position as during Test 2 and consistent with the transport winds. As the data on Figure 4.5.6 show, ozone was again the primary distinguishing feature of the aged plume. This figure describes the distributions of ozone and nitrogen oxides along a traverse at 450 m-msl from the Van Dyke airport, north of Pleasant Grove, southeast to near Cameron Park (Point 5-3 in Figure 4.5.5). The plume was plainly entered about 17 km from Point 5 and continued to Cameron Park with ozone reaching maximum concentrations of 10 pphm between I-80 and Folsom Lake. Lincoln, which was the northwestern edge of the plume found in Test 2, is directly downwind of the edge of the plume found on this pass. Note the strong NO_x plume on Figure 4.5.6 generated by traffic on I-80 and the associated ozone scavenging. Figure 4.5.7 shows the b_{scat} and SO_2 distribution along the same traverse. A noteworthy feature of the sampling on 25 August was the ambient or background concentrations of SO_2. Whereas sampling on previous days had not detected any SO_2 in the Sacramento area, low concentrations (but in excess of 10 ppb) were observed during both the morning and afternoon sampling flights. No significant concentrations were detected upwind of Sacramento.

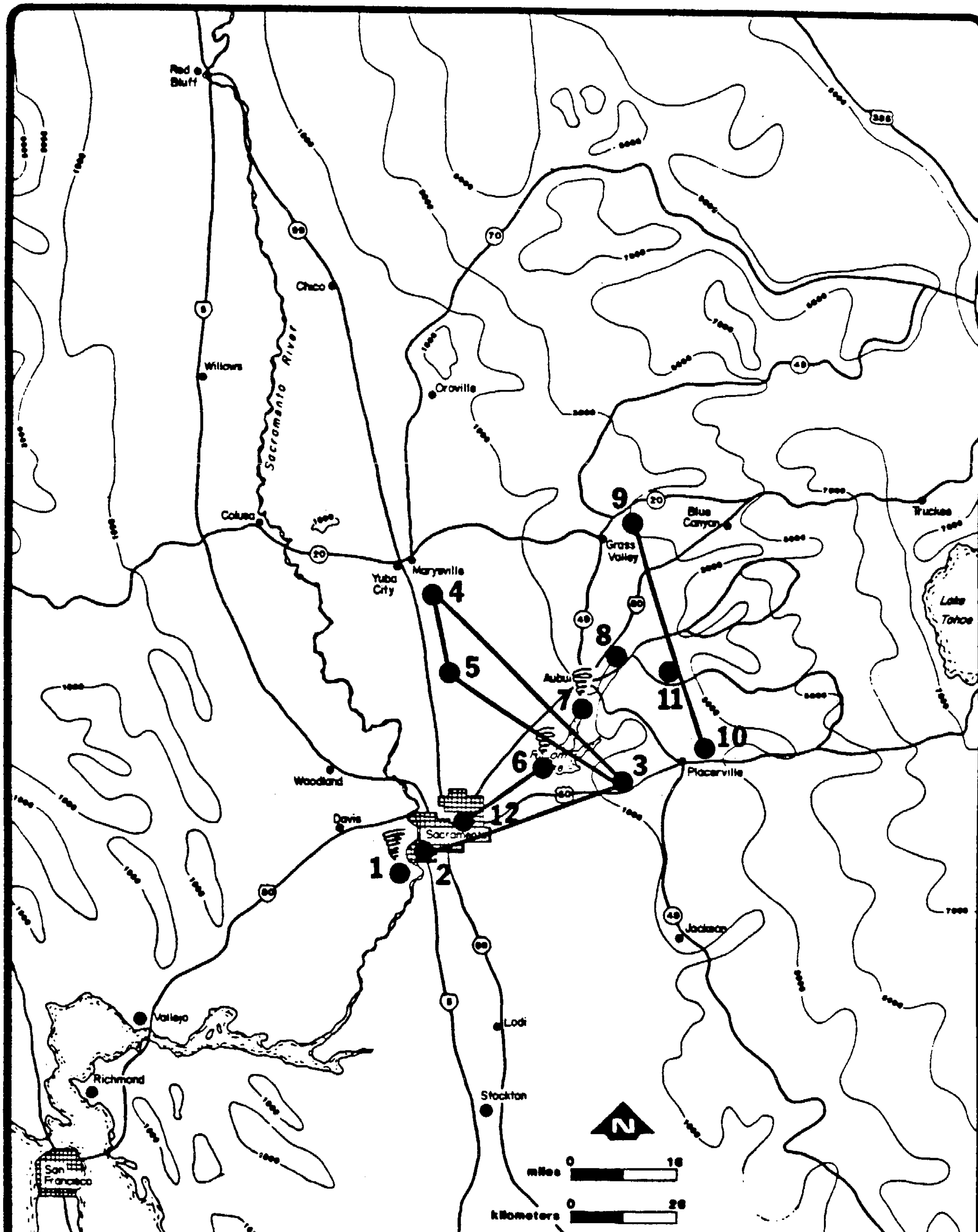


Figure 4.5.5
Sacramento Valley Oxidant Study
MRI 206 Sampling Flight Map

TEST 5 | 25 August 1980 | Tape #155

Table 4.5.3

AIR QUALITY MEASUREMENTS CARB SACRAMENTO VALLEY PROJECT
AUGUST 25, 1980 SAMPLING

Start Time (PDT)	Location (Point)	Altitude (m-msl)	O_3		b_{scat}		NO_x		NO		SO_2	
			Mean (ppb)	Max (ppb)	Mean ($x10^{-6}m^{-1}$)	Max	Mean (ppb)	Max (ppb)	Mean (ppb)	Max (ppb)	Mean (ppb)	Max (ppb)
1351	1	1829-2	66	92	69	129	3	9	2	7	0	5
1407	2-3	457	62	85	94	138	13	31	4	9	1	2
1426	3-4	518	69	95	88	156	9	35	3	10	1	7
1447	4-5	457	65	77	120	228	7	17	3	7	5	9
1459	5-3	457	83	103	105	235	14	37	4	10	7	12
1518	6	149-2134	83	103	78	129	8	20	3	9	4	12
1545	7	2134-198	82	108	84	127	5	13	3	7	2	10
1605	8	610-1829	89	104	80	122	10	18	3	9	2	9
1628	9-10	1067	91	106	86	120	7	16	2	8	1	4
1657	11	808-2134	79	99	79	127	5	11	3	7	1	3
1730	6-12	457	64	88	89	127	17	26	2	8	3	3

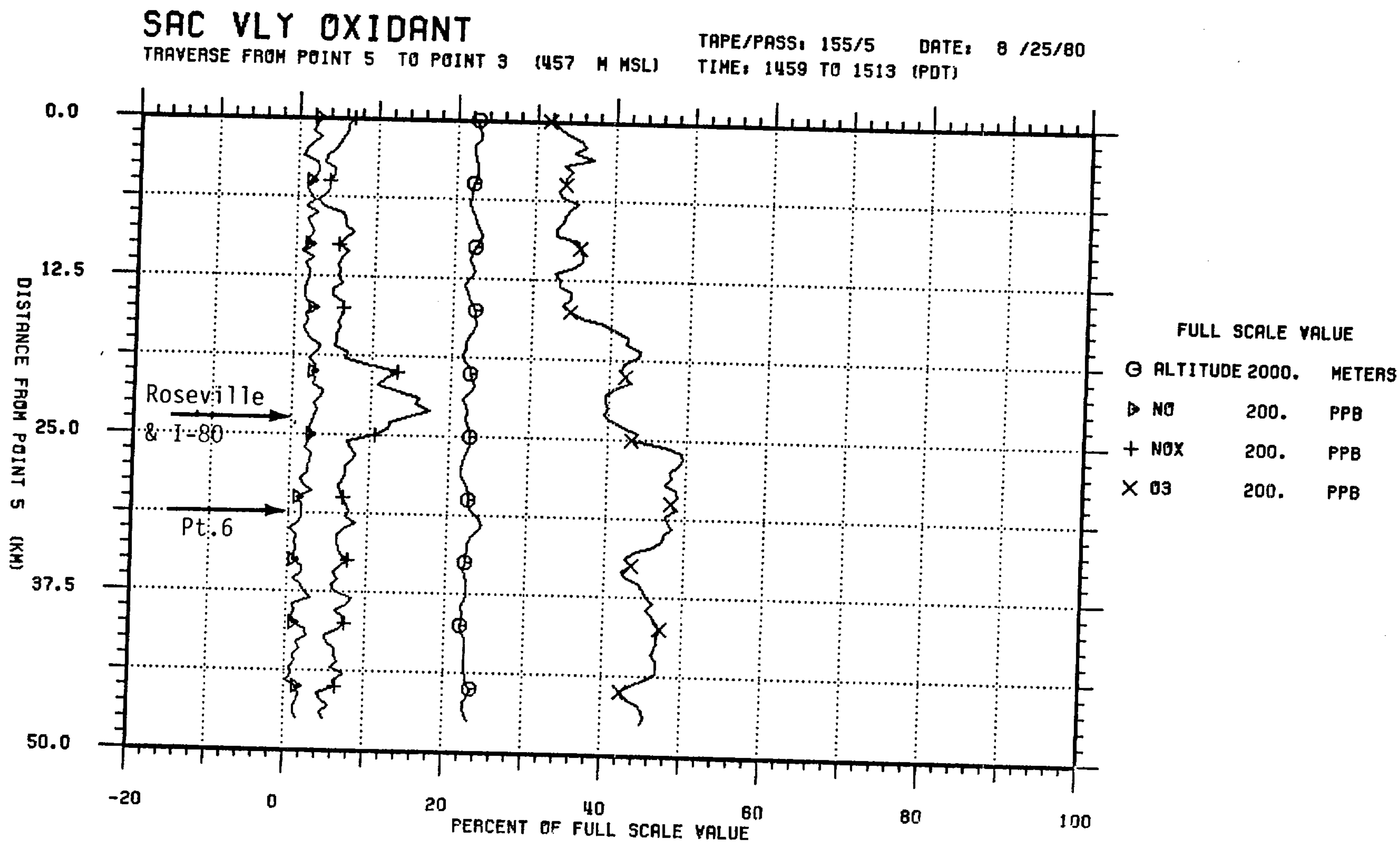


Figure 4.5.6 Airplane Traverse from Van Dyck AP to Cameron Park, 457 m-msl. 25 August 1980. Showing NO, NO_x, O_3.

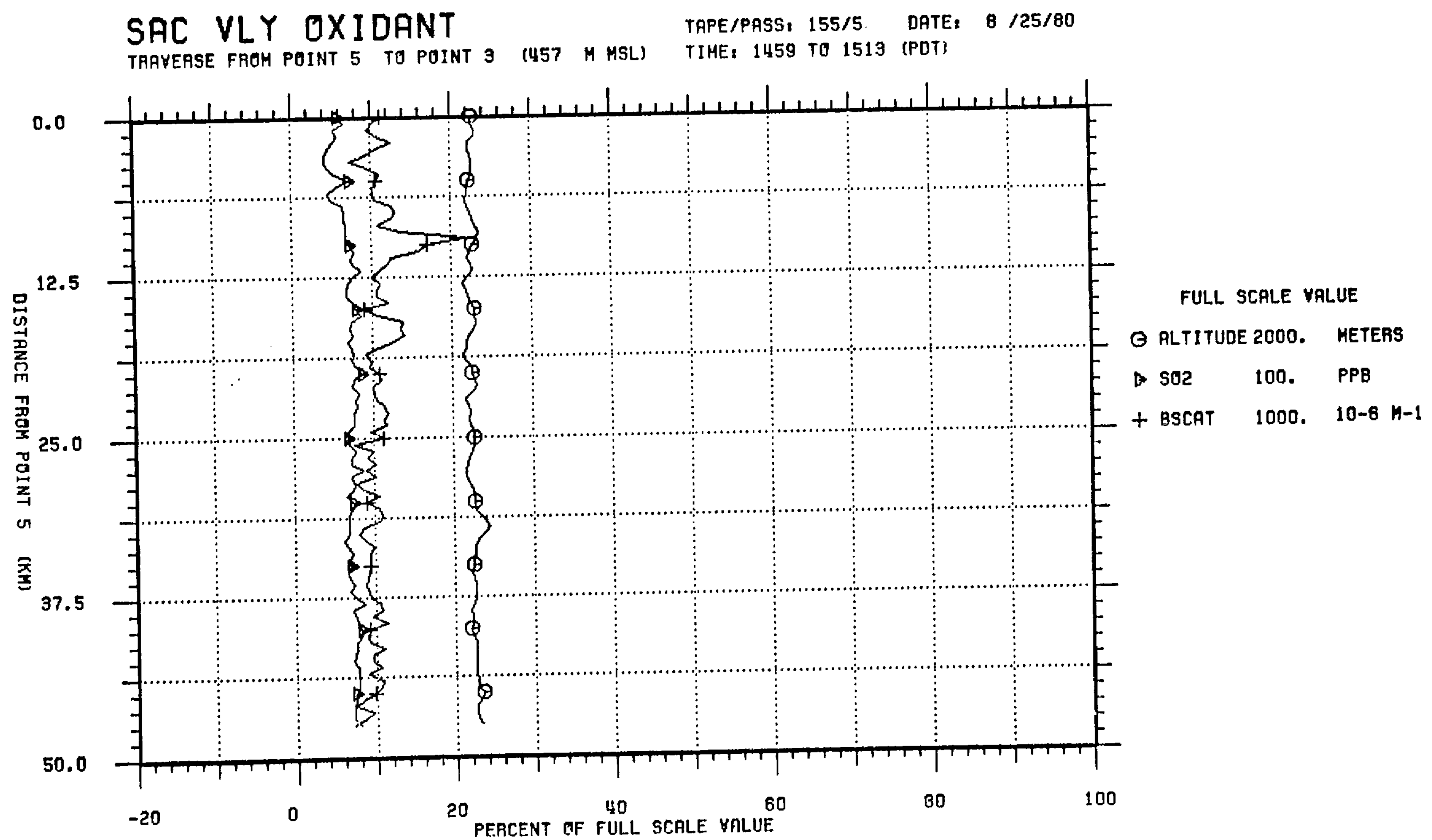


Figure 4.5.7 Airplane Traverse from Van Dyck AP to Cameron Park, 457 m-msl. 25 August 1980. Showing SO_2 and b_{scat}.

Figure 4.5.8 shows the vertical distribution of ozone and the temperature profile southwest of Sacramento and in the Sierra foothills. Point 6 (Figure 4.5.8.b) was over the west shore of Folsom Lake and near where maximum plume concentrations were measured on the above traverse. From the figure it is seen that ozone was well mixed from the surface to 1000 m, averaging 10 pphm. Successive soundings at Point 7 and Point 8, some 13 and 14 km further downwind show the same mixing layer features. Figure 4.5.8.a is the temperature-ozone profile from about 15 km upwind of downtown Sacramento. There the mixing layer was defined by an inversion based at 350 m. Ozone averaged 4 pphm within the mixing layer. Maximum ozone was measured aloft in a layer between 1000-1400 m-agl. No significant concentrations of NO_x and SO_2 were measured upwind.

The ozone and nitrogen oxides distributions on the traverse from Point 6 (Folsom Lake) to Sacramento are presented in Figure 4.5.9. Ozone is shown to decrease rapidly as the airplane traversed back to Sacramento, documenting the transport of smog away from the source region. The ozone concentration at Folsom Lake decreased from earlier sampling to 9 pphm inferring that the urban plume peak had passed and moved further into the foothills. Ozone concentrations in the city averaged about 5 pphm during this traverse.

The major features of the aircraft soundings are shown in Table 4.5.4. This table shows the mixing height, average ozone concentrations in the mixing layer, and the integrated column content of ozone above background levels from the surface to the top of mixing. Also included in the table are the downwind distances of each sampling location relative to Point 1 which was just upwind of the Sacramento metropolitan area. The distances the column of air sampled over Point 1 would have been transported based on the mean winds and sampling times are also included. A comparison of the actual distances and the wind run show that the air sampled at Point 1 was transported only 17-34 km downwind, whereas, the downwind spirals were at 50-79 km distances. However, assuming relatively steady state upwind conditions prior to sampling, the ozone loading shown in Table 4.5.4 could be attributable to sources in the Sacramento metropolitan area. Peak surface ozone concentration at Auburn was experienced between 18-1900 PDT or 2 hours after the aircraft sampling (see Figure 4.5.10). Thus the maximum impact from the urban plume had not yet reached downwind as far as Auburn when sampling was conducted.

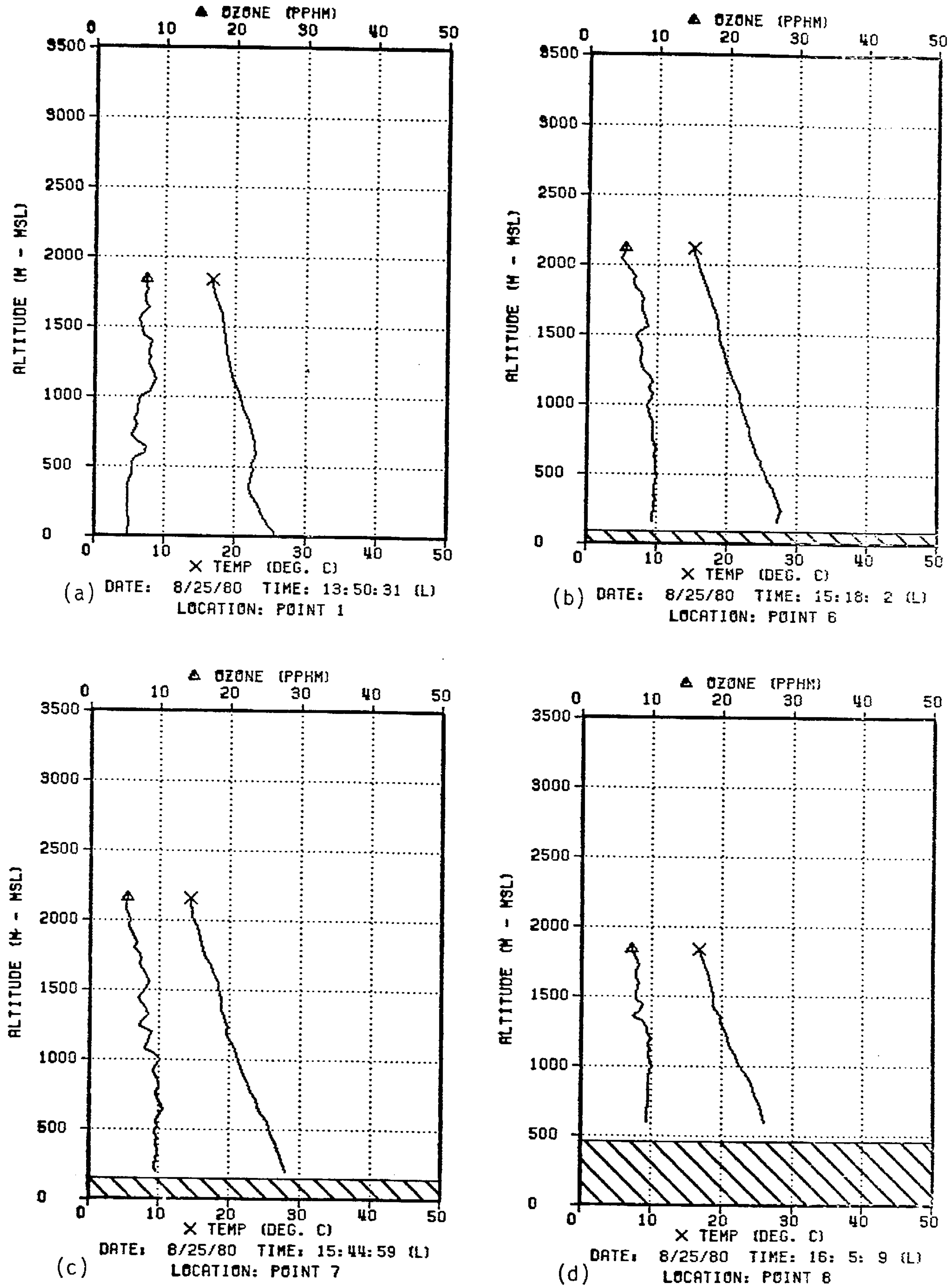


Figure 4.5.8 Temperature-Ozone Profiles over a) 5 mi SW Sacramento Exec. AP, b) NW Folsom Lake, c) E Folsom Lake, d) Bowman Reservoir. 28 August 1980.

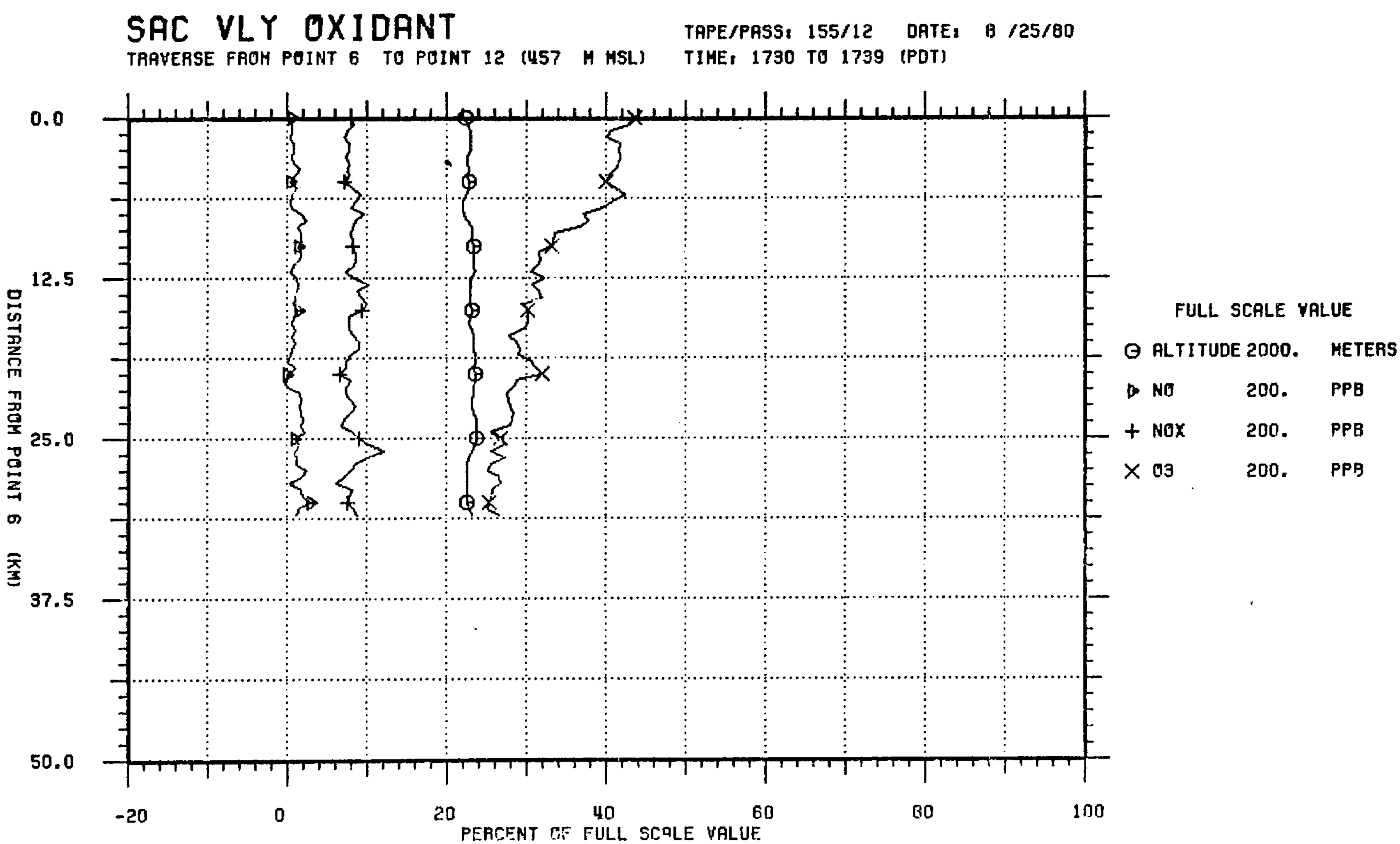


Figure 4.5.9 Traverse from Folsom Lake to Sacramento, 457 m-msl. 25 August 1980. Showing NO, NO_x, O_3.

Table 4.5.4 Summary of Aircraft Soundings - 25 August 1980

Location	Time (PDT)	Distance (Km) Actual	Distance (Km) Wind Run	Mixing Ht. (m-agl)	Average Ozone Concentration (pphm)	Ozone Loading Above Background* (mg/m^2)
SAC VOR (Point 1)	1355	0	0	550	5.0	0
Folsom Lake (Point 6)	1530	50	17	1050	9.5	93.1
East End Folsom Lake (Point 7)	1551	62	21	1050	9.5	93.1
Bowman Reservoir (Point 8)	1611	72	25	1000	9.5	88.7
Georgetown Airport (Point 11)	1705	79	34	1000	8.8	74.9

*Background concentrations = 5.0 pphm

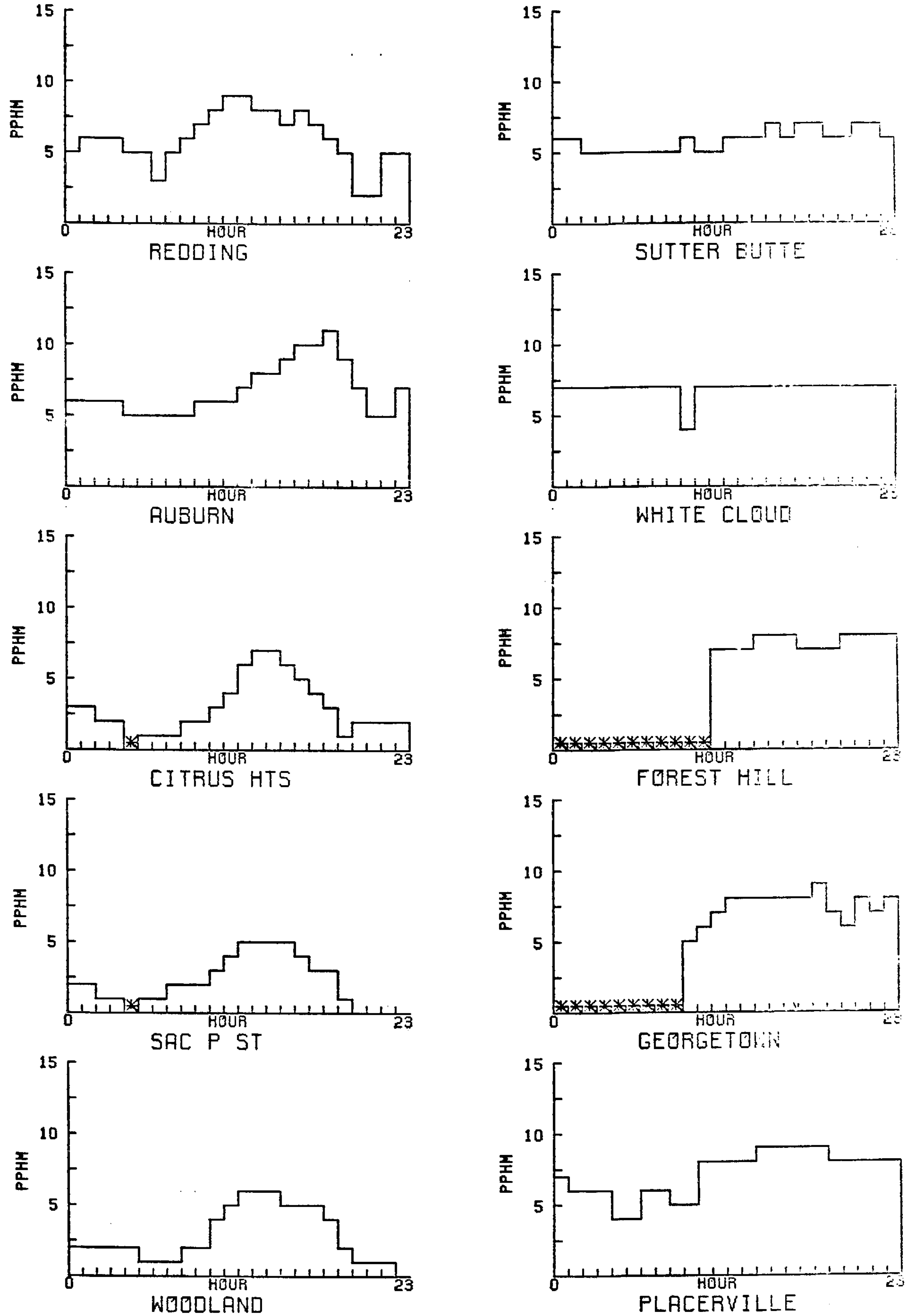


Figure 4.5.10 Hourly Averaged Oxidant Concentrations at Selected Locations. 25 August 1980. (* indicates missing data).

Regional Surface Oxidant Levels

Hourly averaged surface ozone concentrations for selected locations within the study area are shown in Figure 4.5.10. The State standard was exceeded for one hour at Auburn (11 pphm). As discussed above, Auburn was impacted by the urban plume from Sacramento which is reflected in the late timing of the peak. Georgetown Ranger Station, Placerville and Redding all experienced 9 pphm oxidant concentrations. The early timing of high ozone levels at Redding (11-1300 PDT) suggest the source was from air aloft fumigated to the surface by convective mixing. Woodland, Sacramento, and Citrus Heights ozone peaks appear to result from local sources and reflect generally good air quality.

4.5.3 Tracer Results

Approximately 400 lbs of SF_6 were released from an ARB building at 15th and R St. in Sacramento between 0700 and 1100 PDT on August 25. A map of the hourly tracer concentrations during the test is shown in Figure 4.5.11. The principal impact on hourly concentrations was noted at Marysville.

Estimated trajectories for the SF_6 plume are shown in Figure 4.5.12. The principal plume which resulted from the early part of the release moved northward, passing east of Marysville, then turning to the north-northwest. Considerable evidence of this plume was obtained during auto traverses near and shortly before midnight.

A portion of the plume released at a later time in the release period traveled to the northeast as far as White Cloud by 1900 PDT.

The principal auto sampling routes on the following morning (August 26) were carried out in the Sierra foothills northeast of Sacramento. No significant tracer was found in these traverses. No morning auto traverses were made in the Red Bluff area on the 26th so evidence of a carry-over was lacking. Significant concentrations were observed in the area as late as 0200 so that a carry-over into the following morning is likely.

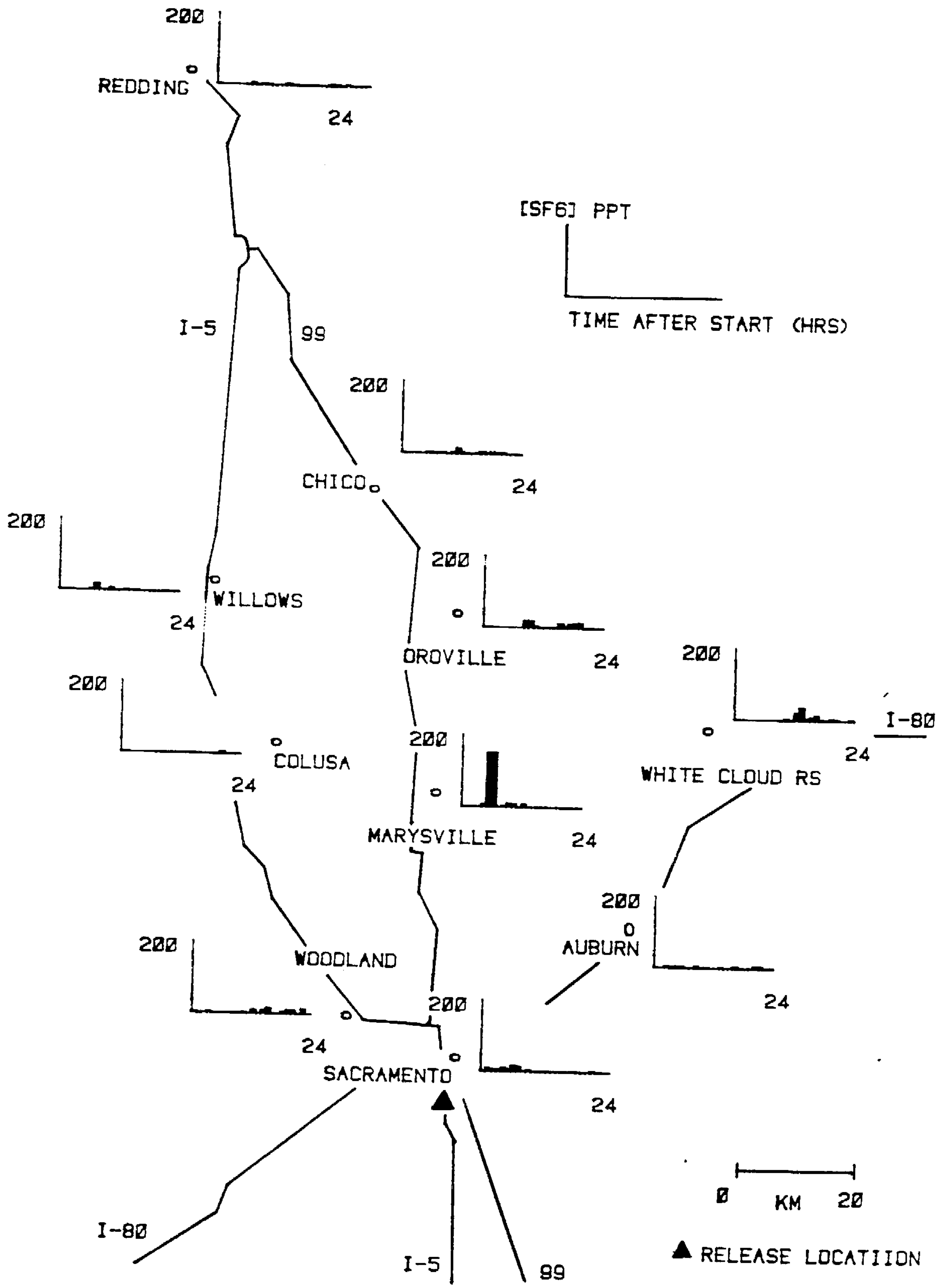


Figure 4.5.11 Hourly Average SF_6 Concentrations
Test 5 - August 25, 1980.

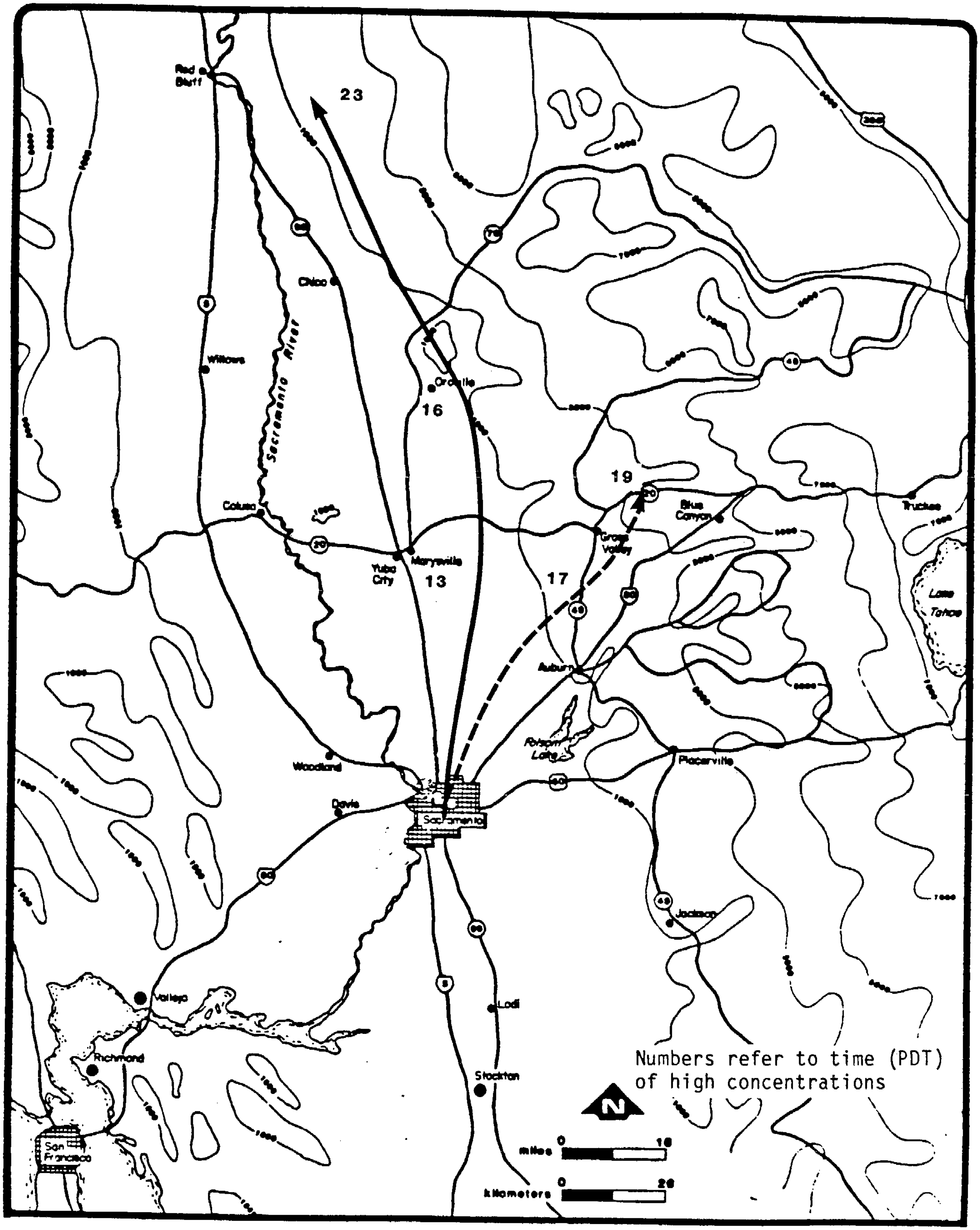


Figure 4.5.12 Tracer Trajectories - Test 5
August 25, 1980 - 0700-1100 PDT

4.6 Test 6 28 August 1980, Woodland Release (0600-1100 PDT)

4.6.1 Meteorology

General

As the weather charts in Figure 4.6.1 show, Northern California was under the influence of an upper level trough positioned along the western U.S. coast. The cold air associated with the trough is reflected in the 850 mb temperatures at Oakland plotted in Figure 2.4.3. This sytem caused broken to scattered middle clouds in the Sacramento Valley and kept surface temperatures well below average. Maximum temperatures reported were 82° and 85°F at Sacramento and Redding, respectively. The data in Table 2.4.2 show that the SFO-SAC pressure gradients remained near the average experienced during the study period, whereas the north-south (SAC-RBL) gradients were weaker than the average.

Mixing Heights

Temperature soundings from the tracer release at Woodland, taken every 6 hours, are shown in Figure 4.6.2. The test began under a strong (11°C) surface based inversion which lifted to 350 m by 1100 PDT. The late afternoon (1700 PDT) observation showed an inversion based at about 450 m still intact. Aircraft soundings taken from 1130-1430 PDT, prior to the time of maximum surface heat flux, show a maximum mixing layer depth of 650 m southwest of Sacramento. The mixing height at the spiral location east of the release site was 550 m.

Transport Winds

This experiment was designed to observe the transport during the occurrence of the so called "Schultz Eddy". This eddy is characterized by the early morning development of a counter-clockwise circulation in the south end of the Sacramento Valley which typically dissipates before noon. As can be seen from Figure 4.6.3, the eddy did develop on the morning of 28 August. Figures 4.6.3 and 4.6.4 show the 0900 PDT and 1300 PDT winds at the approximate 260 m-agl level from pibals taken at Sacramento, Dunnigan, Woodland, and Davis. Streamlines based on those winds depict the transport in the Woodland-Sacramento region. The first figure represents the transport during the tracer release and the second figure describes the flow in the

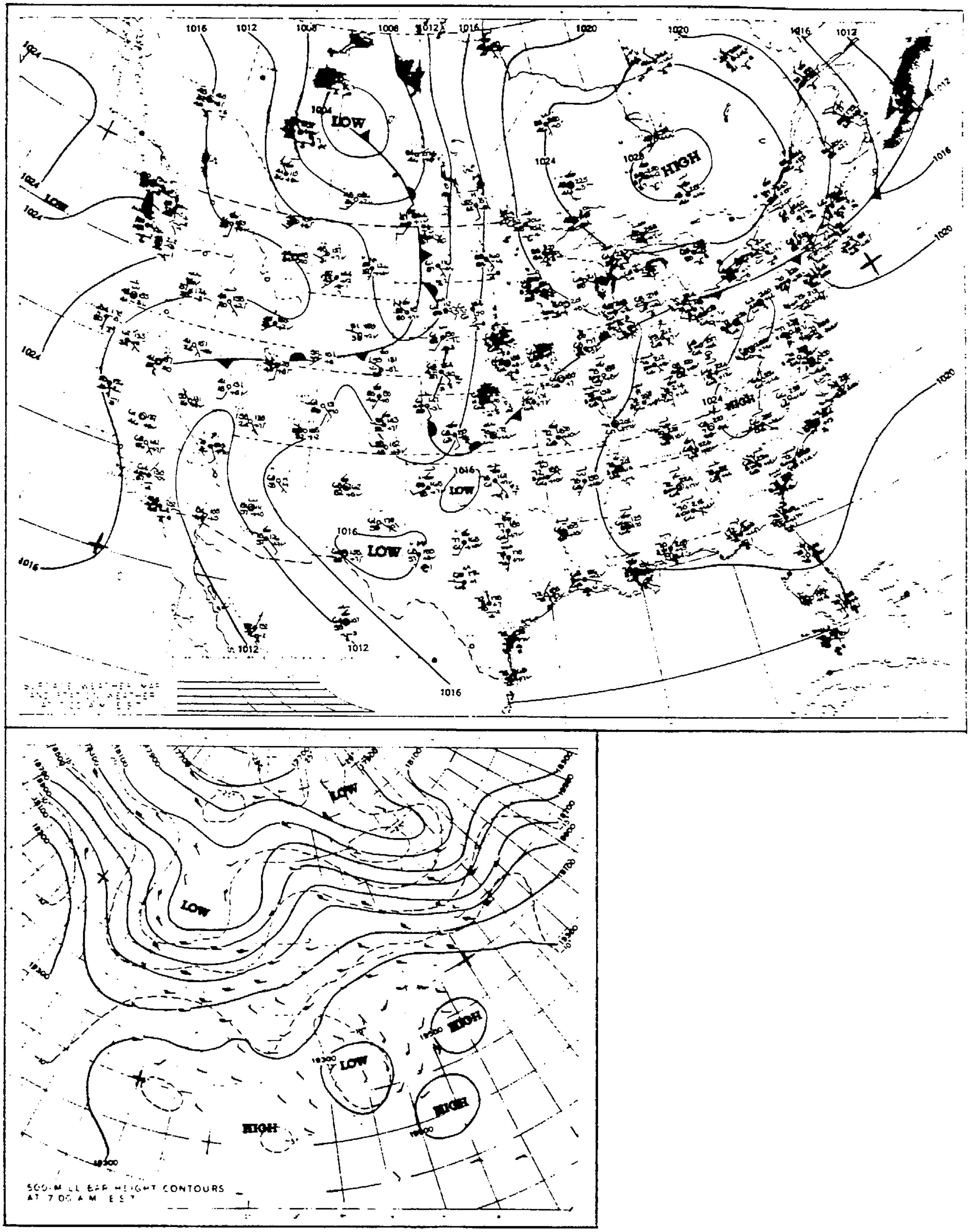
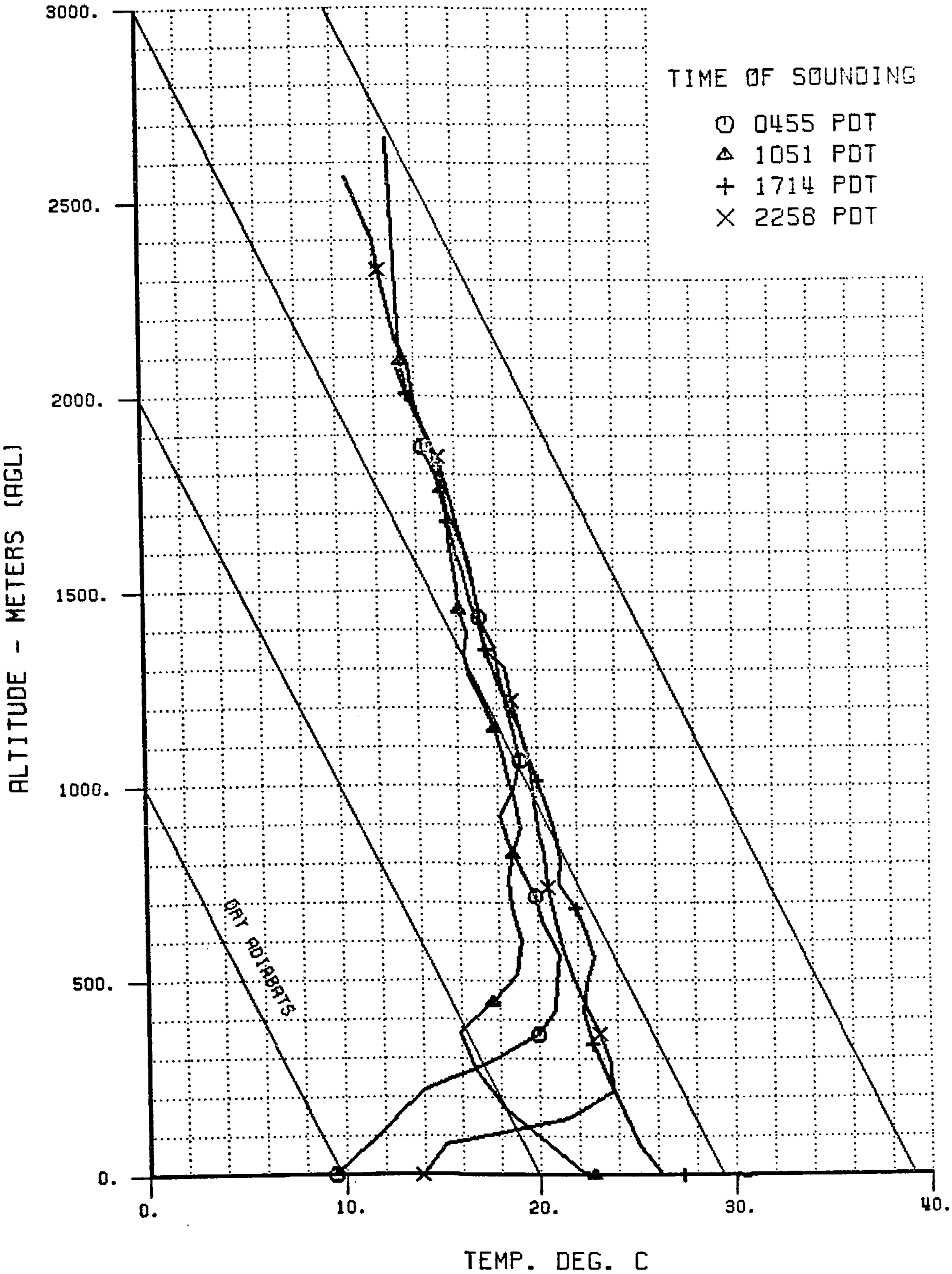


Figure 4.6.1 Surface and 500 mb Weather Charts - 28 August 1980 (0500 PDT)



LOCATION: WOODLAND AIRPORT
DATE: 8/28/80

Figure 4.6.2 Temperature Profiles.

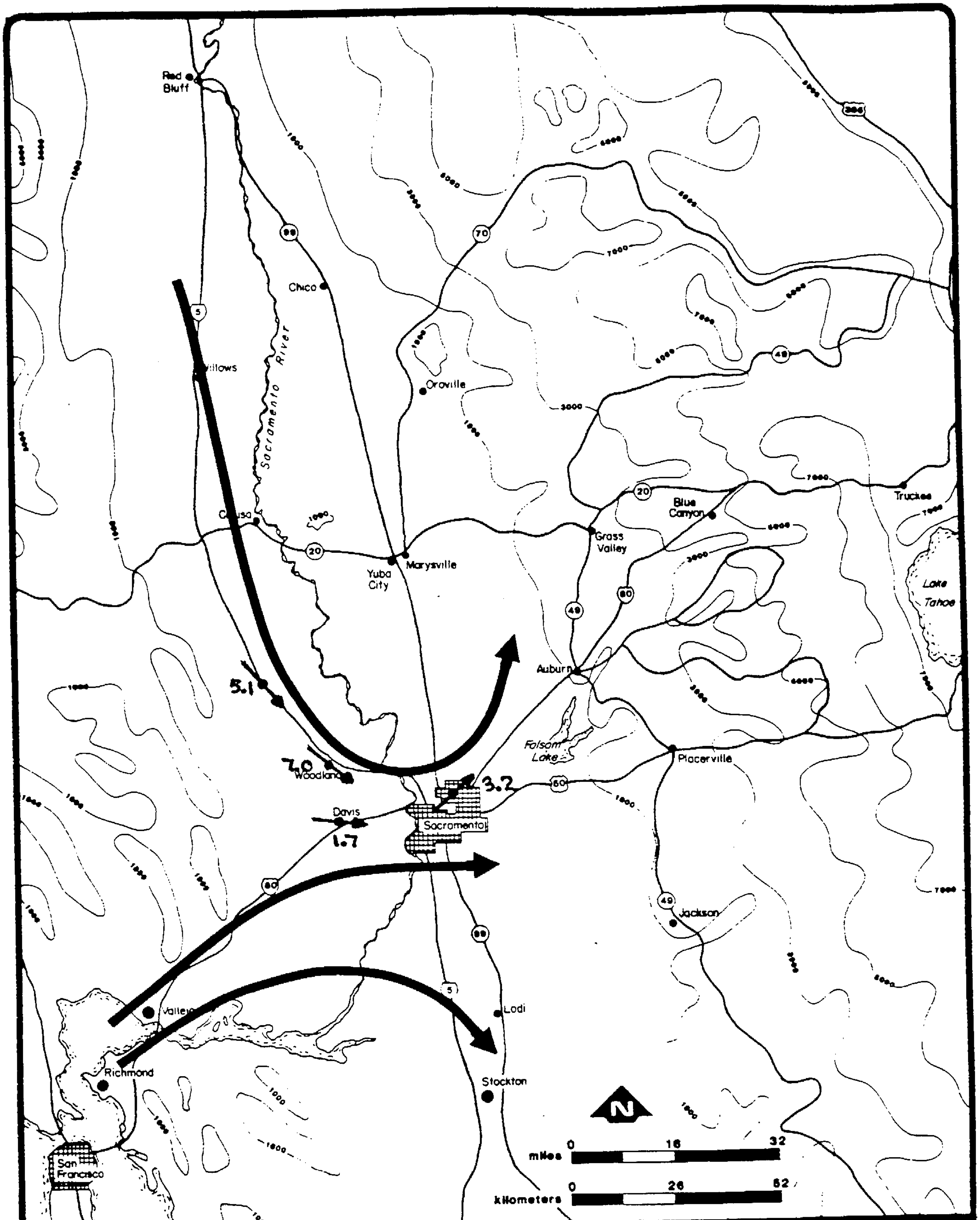


Figure 4.6.3 260 m-agl Winds and Streamlines - 28 August 1980 at 0900 PDT.

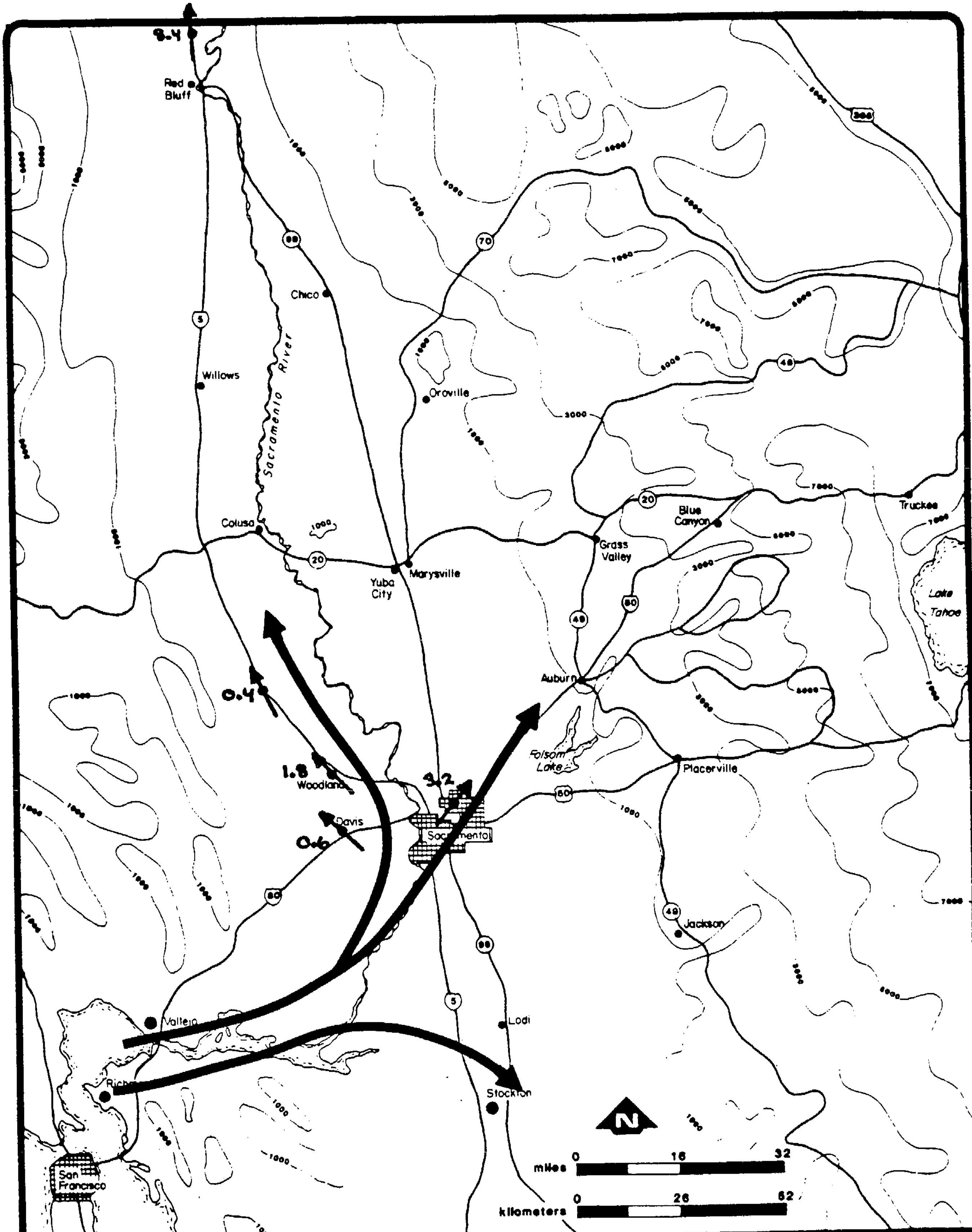


Figure 4.6.4 260 m-agl Winds and Streamlines - 28 August 1980 at 1300 PDT.

afternoon after the eddy had broken down. Vertical time sections of the pibal winds from Woodland, Davis and Dunnigan are shown in Figures 4.6.5 - 4.6.7. From these figures the vertical and temporal extent of the eddy can be examined. Assuming a northerly component to the wind is indicative of the eddy development at Woodland (Figure 4.6.5), the eddy depth was at least 660 m at 0500 PDT and continued in the lower 500 m through the 0900 PDT observation. By 1100 PDT, only remnants of the eddy remained. After 1300 PDT, a general southerly flow persisted at low levels. Davis winds (Figure 4.6.6) show a westerly low level flow prior to 1100 PDT. The 1100 PDT observation begins to show a shift to more southerly winds which thereafter prevailed. The Dunnigan pibal winds (Figure 4.6.7) show a general northerly flow at low levels continuing until the 0900 PDT observation. By 1300 PDT, the low level flow is mostly from southeast to east. All three locations show afternoon wind speed maxima between 17-1900 PDT. Woodland and Dunnigan show morning maxima from 07-0900 PDT. It is interesting to note that the two maxima at Dunnigan, in addition to being 12 hours apart, are at the same height, of equal magnitude, and 180^{0} different in wind direction. One can only speculate if this is a repeatable diurnal cycle.

Surface winds at the release site, listed in Table 4.6.1, provide a continuous record of the wind on 28 August. On the evening of 27 August and up until 0100 on 28 August, the wind was from the east. A weak northerly flow developed in the early morning and continued until 1100 PDT. Thereafter the wind reversed to southeasterly and remained as such during the afternoon. Similar to the winds aloft, the surface winds showed a bimodal peak; one at 0900 and another at 1800 PDT.

4.6.2 Air Quality

Airplane Sampling

Due to an inoperative ozone monitor, the airplane sampling pattern was designed to primarily collect airborne grab samples to observe tracer flux. Sampling was conducted from 1126-1532 PDT on 28 August along a route which thrice circumvented the Sacramento area as shown on Figure 4.6.8. Spirals were flown at Points 1 and 2 at the start of sampling and after the second orbit around Sacramento was completed. Pollutant concentrations measured on each segment of the flight are given in Table 4.6.2. Maximum SO_2 concentrations were measured south of Sacramento near Points 1 and 3 (Stone

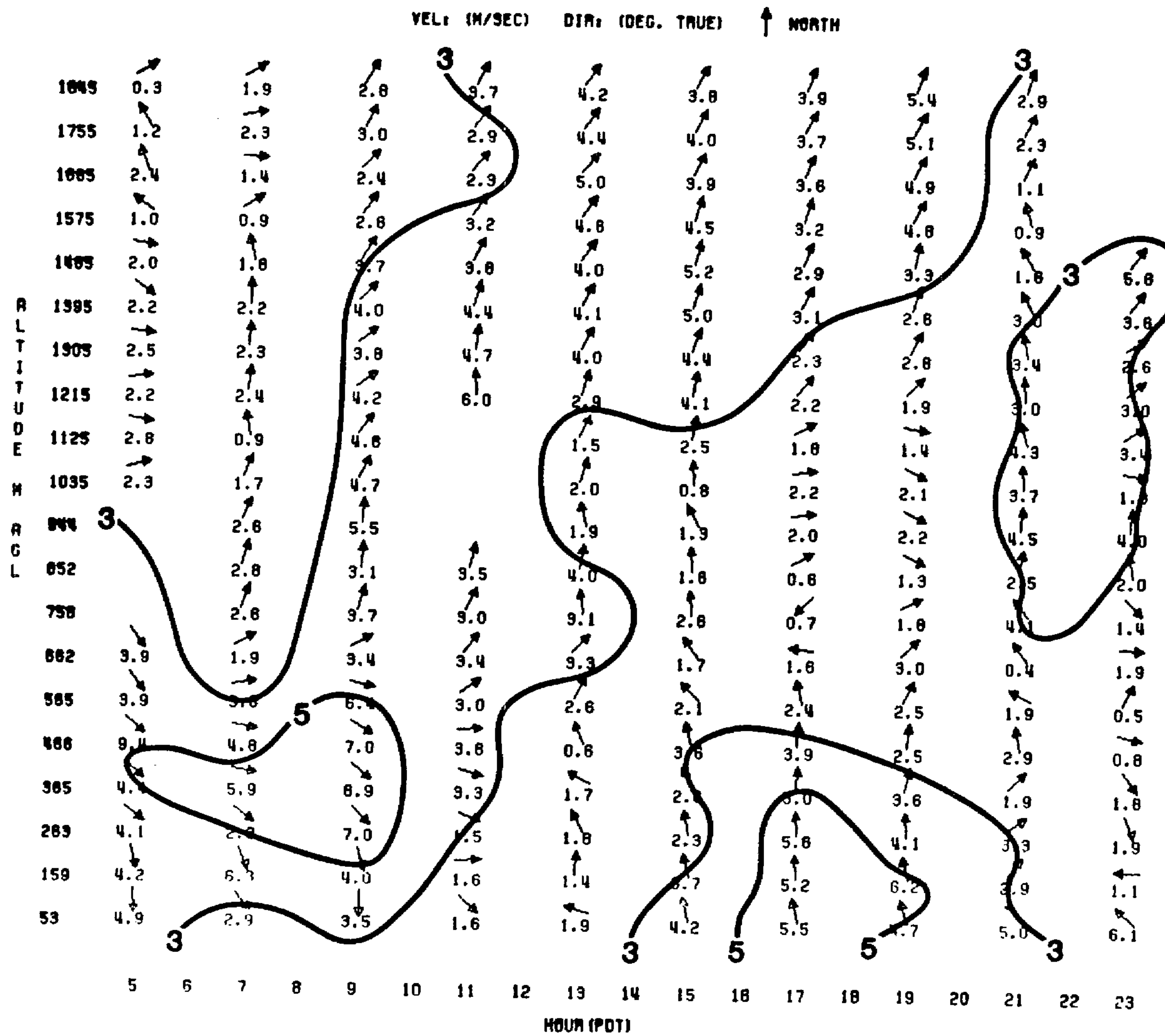


Figure 4.6.5 Vertical Time Section of Winds Aloft at Woodland on 28 August 1980. Wind Speed in m/s.

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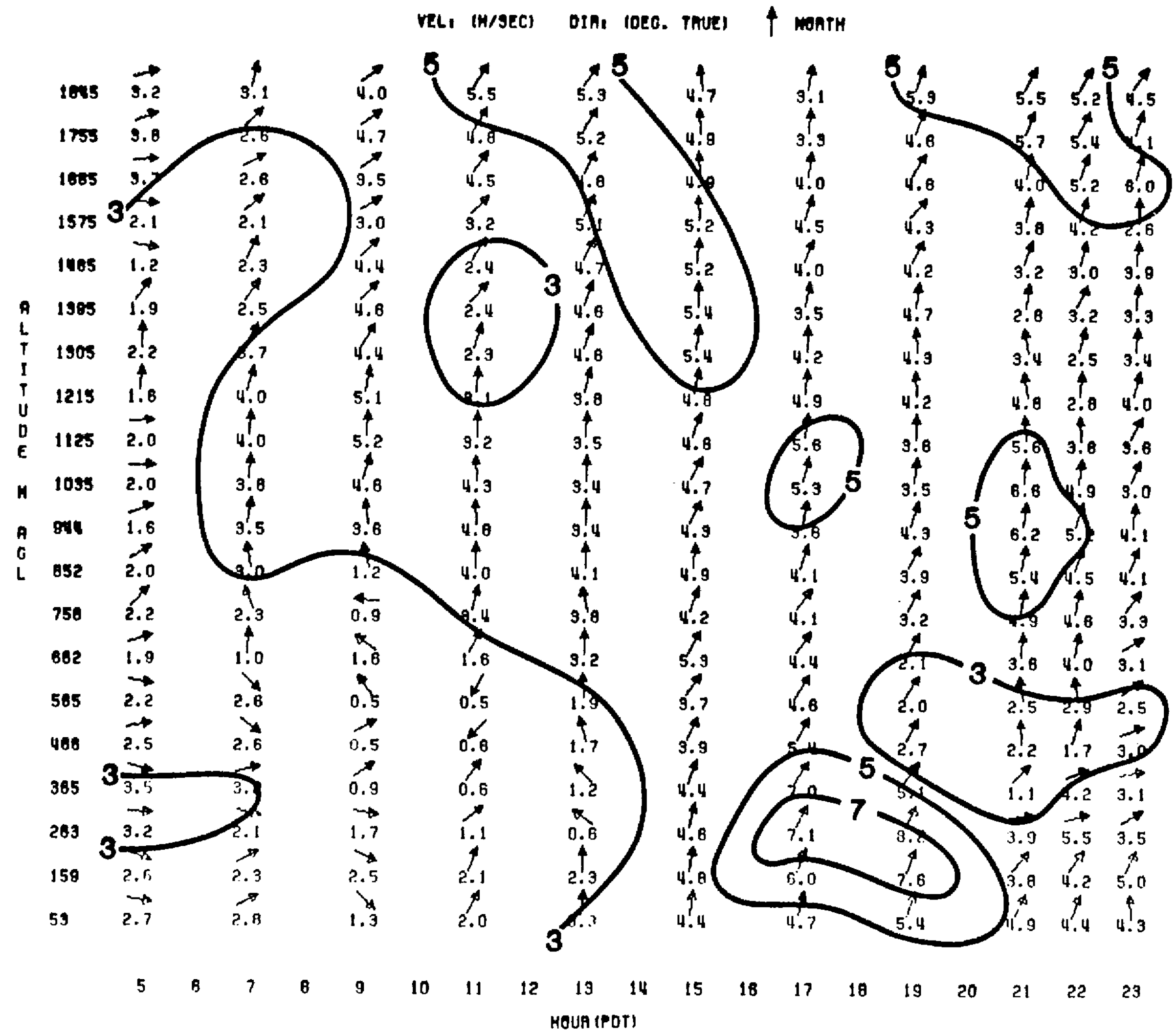

Figure 4.6.6 Vertical Time Section of Winds Aloft at Davis on 28 August 1980. Wind Speed in m/s.

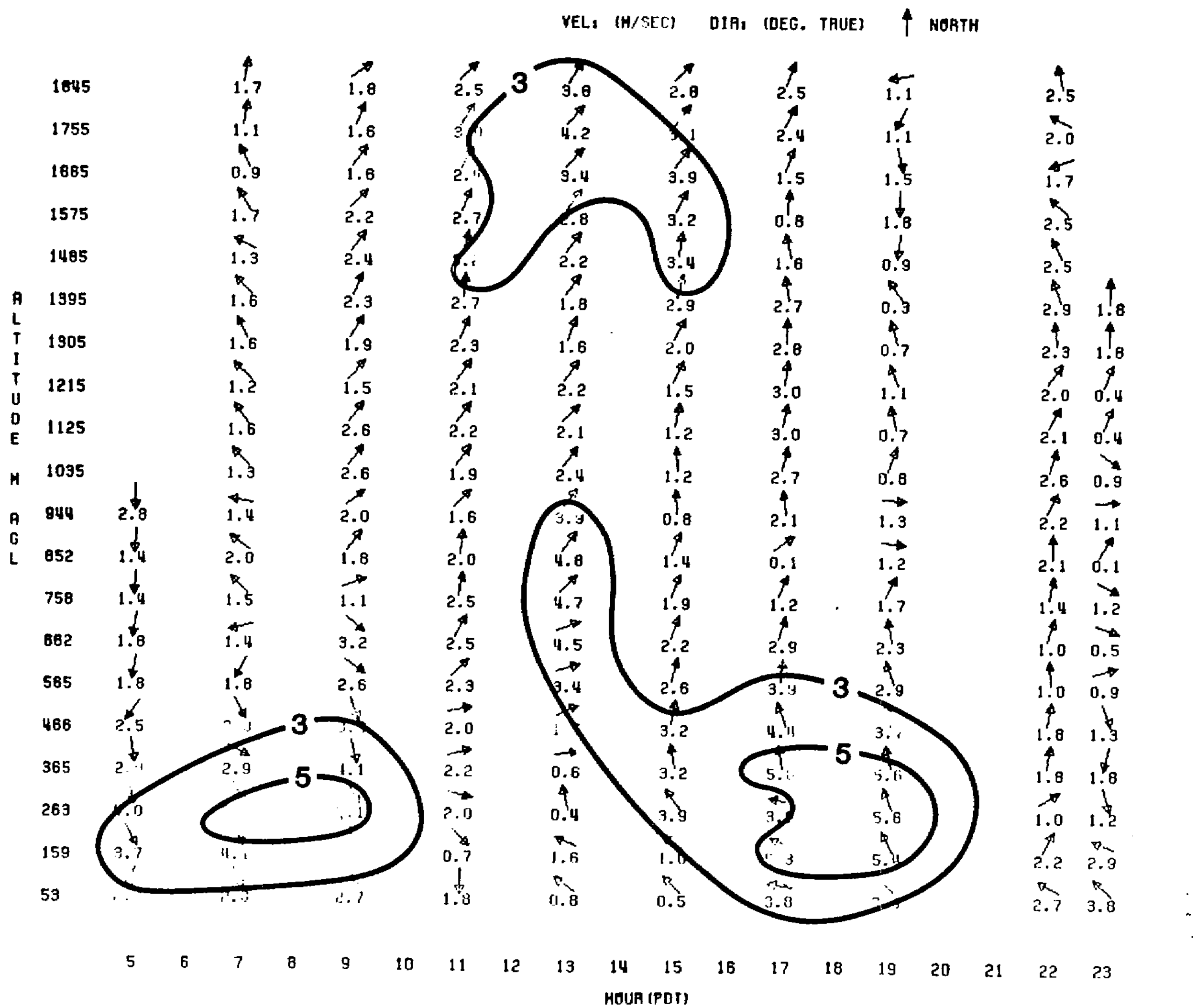

Figure 4.6.7 Vertical Time Section of Winds Aloft at Dunnigan on 28 August 1980. Wind Speed in m/s.

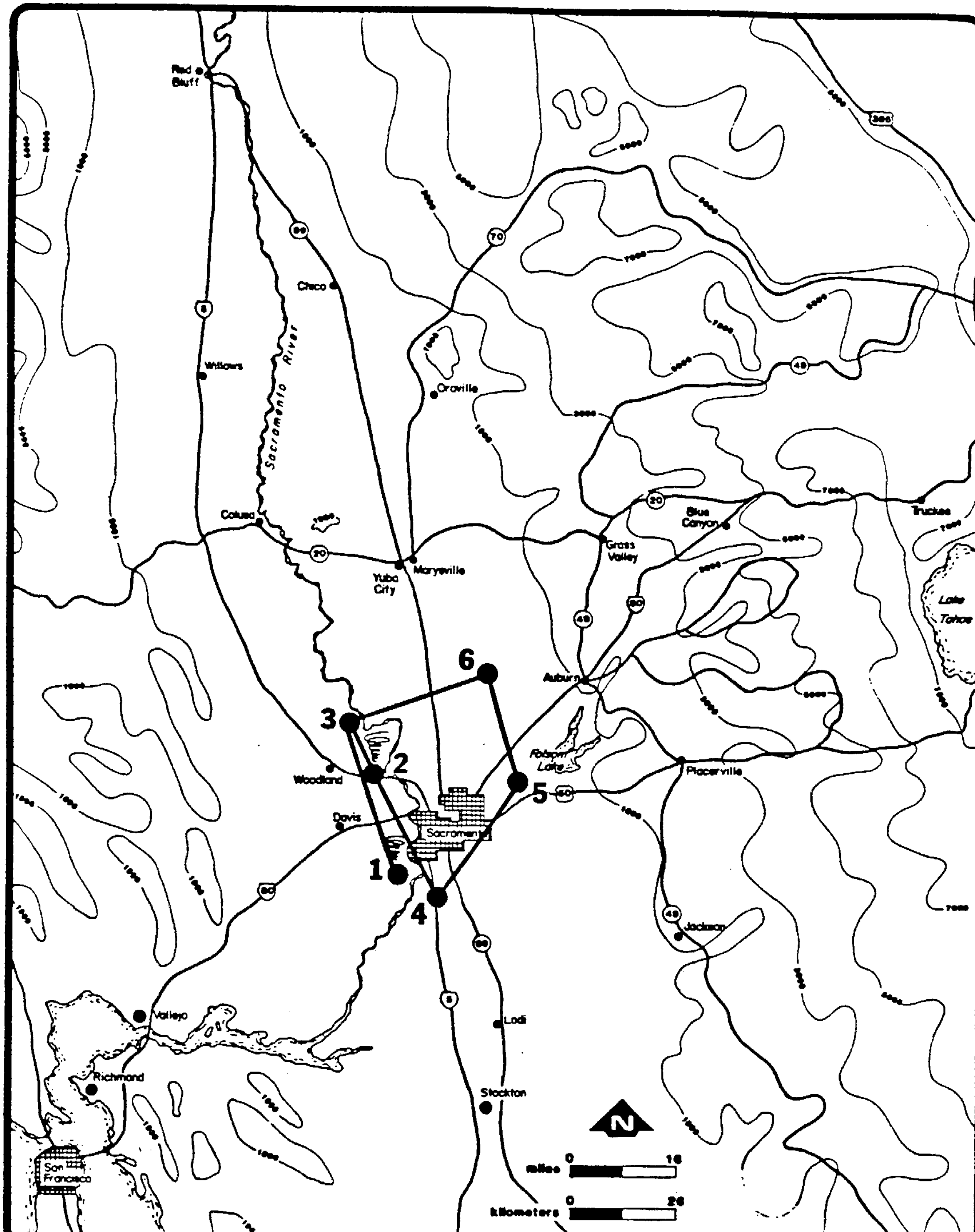

Figure 4.6.8
Sacramento Valley Oxidant Study
MRI 206 Sampling Flight Map

TEST 6 | 28 August 1980 | Tape #156

Table 4.6.1
Surface Winds at Woodland
28 August 1980

Time (PDT)	Wind (m/s)	Time (PDT)	Wind (m/s)
00	090/1.1	10	315/0.8
01	060/0.8	11	300/1.4
02	360/0.7	12	120/1.0
03	calm	13	150/2.0
04	340/0.5	14	160/2.5
05	330/0.9	15	150/2.6
06	290/0.7	16	150/2.9
07	300/1.1	17	150/3.7
08	300/1.8	18	150/3.5
09	350/2.1	19	150/3.5

Lake near Hood) whereas maximum b_{scat} and NO_x levels were observed north of Sacramento.

This flight provided perhaps the only evidence of SO_2 transport from sources in the delta or Bay area into the Sacramento Valley although concentrations were low. Figures 4.6.9 - 4.6.11 show the SO_2 and b_{scat} distribution at 400 m altitude on three traverses south of Sacramento between Points 4-5 at sampling start times of 1229, 1326, and 1442 PDT, respectively. On the 1229 PDT traverse no significant concentrations of SO_2 were measured. At 1326 PDT, some SO_2 (8 ppb) was observed within 6 km of Point 4. By 1442 PDT, a distinct SO_2 plume was measured extending approximately 20 km northwest from Point 4. The spirals at Point 1 (approximately 10 km southwest of the Sacramento Executive Airport) show a similar trend. The earlier spiral (Figure 4.6.12) shows no detectable concentration of SO_2 whereas the spiral taken 3 hours later (Figure 4.6.13) shows concentrations to 12 ppb in the low levels. The flow was from the southwest in this region throughout the sampling.

Another interesting feature of this sampling flight was the detection of two distinct NO_x plumes; one northwest of Sacramento near Point 3 and another northeast of Sacramento near Point 6. Examples of these plumes

Table 4.6.2

AIR QUALITY MEASUREMENTS CARB SACRAMENTO VALLEY PROJECT

AUGUST 28, 1980 SAMPLING

Start Time (PDT)	Location (Point)	Altitude (m-msl)	O_3 Mean (ppb)	O_3 Max (ppb)	b_{scat} Mean ($\times 10^{-6} m^{-1}$)	b_{scat} Max ($\times 10^{-6} m^{-1}$)	NO_x Mean (ppb)	NO_x Max (ppb)	NO Mean (ppb)	NO Max (ppb)	SO_2 Mean (ppb)	SO_2 Max (ppb)
1126	1	12-1524	-	-	63	163	4	13	2	6	0	1
1151	2	1524-18	-	-	99	188	9	23	2	7	0	2
1209	3-4	396	-	-	129	226	13	27	4	11	0	2
1229	4-5	396	-	-	126	181	13	24	4	9	0	3
1243	5-6	396	-	-	101	158	21	32	5	9	1	3
1253	6-3	396	-	-	122	208	17	29	4	9	1	5
1305	3-4	396	-	-	118	197	11	23	3	8	1	5
1326	4-5	396	-	-	111	163	14	23	4	7	2	8
1339	5-6	396	-	-	104	158	21	31	5	8	3	9
1349	6-3	396	-	-	107	217	14	31	3	7	2	8
1406	2	12-1524	-	-	58	127	5	15	1	4	1	7
1428	1	1524-14	-	-	68	147	6	15	1	6	2	12
1442	4-5	396	-	-	121	179	15	29	3	9	5	12
1455	5-6	396	-	-	107	160	23	37	4	8	5	10
1505	6-3	396	-	-	98	151	13	25	3	7	3	7
1518	3-1	396	-	-	86	149	10	16	2	6	2	9

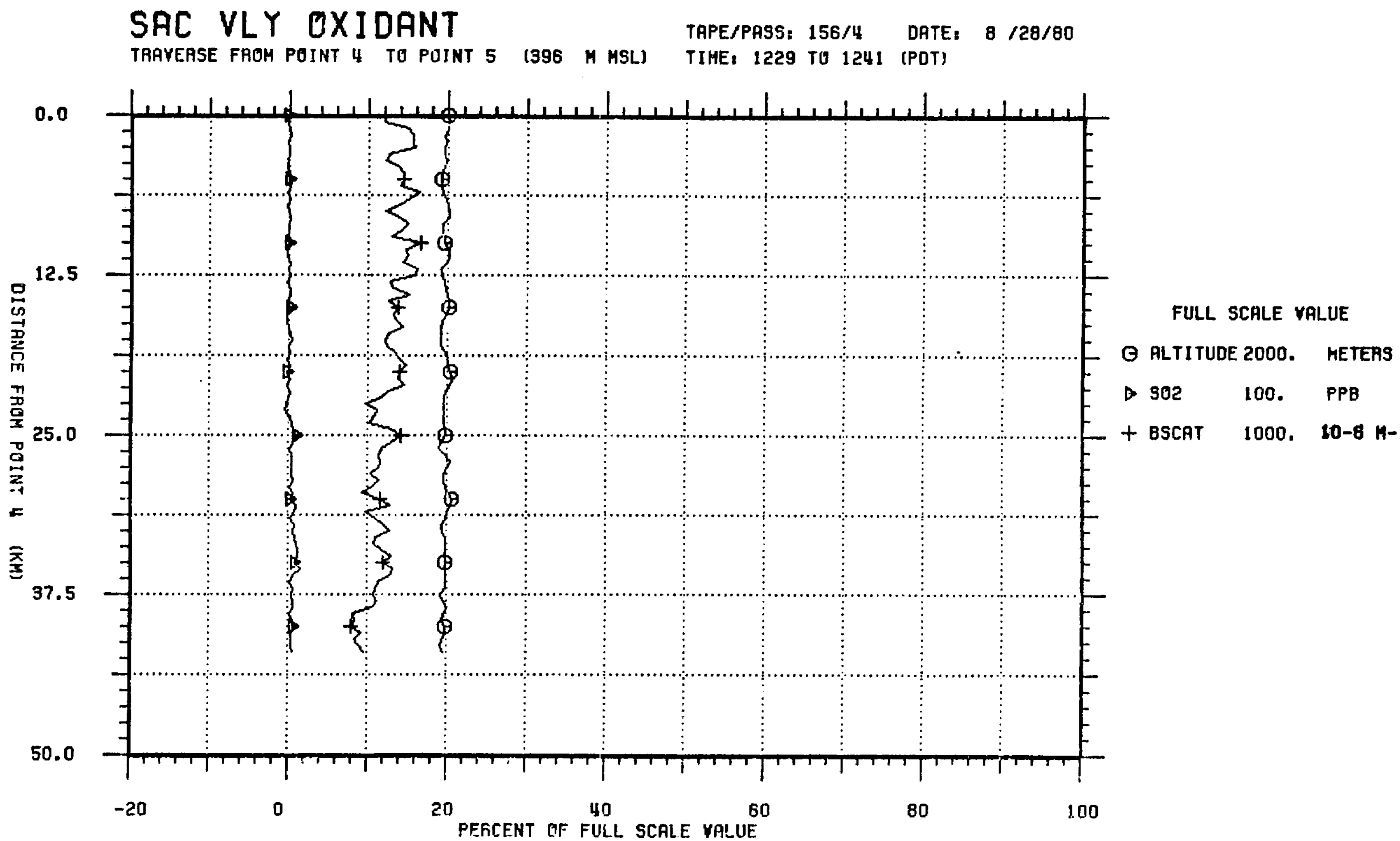

Figure 4.6.9 Airplane Traverse from Near Hood to Fair Oaks, 396 m-msl. 28 August 1980, 1229-1241 PDT. Showing SO_2, b_{scat}.

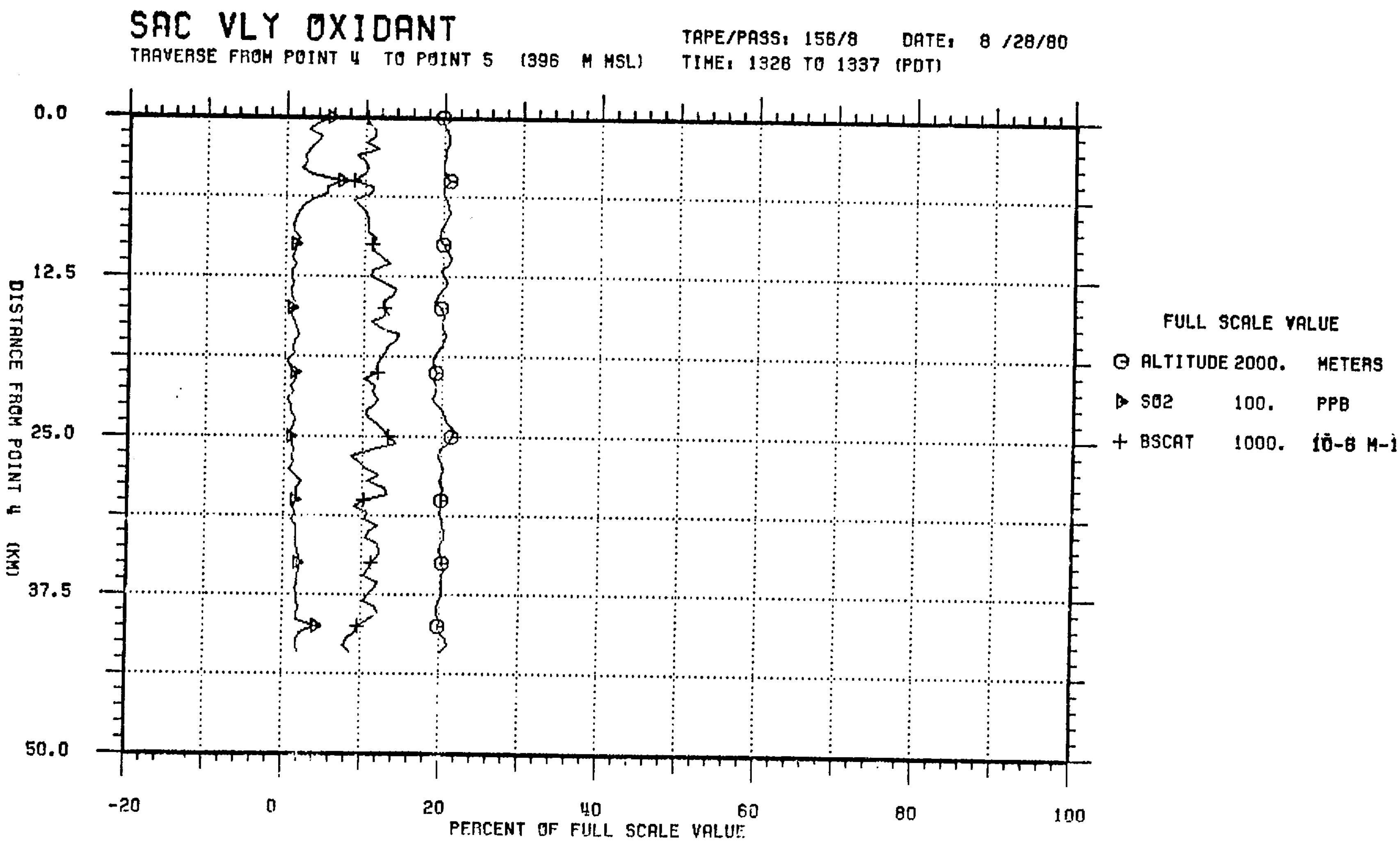

Figure 4.6.10 Airplane Traverse from Near Hood to Fair Oaks, 396 m-msl. 28 August 1980, 1326-1337 PDT. Showing SO_2, b_{scat}.

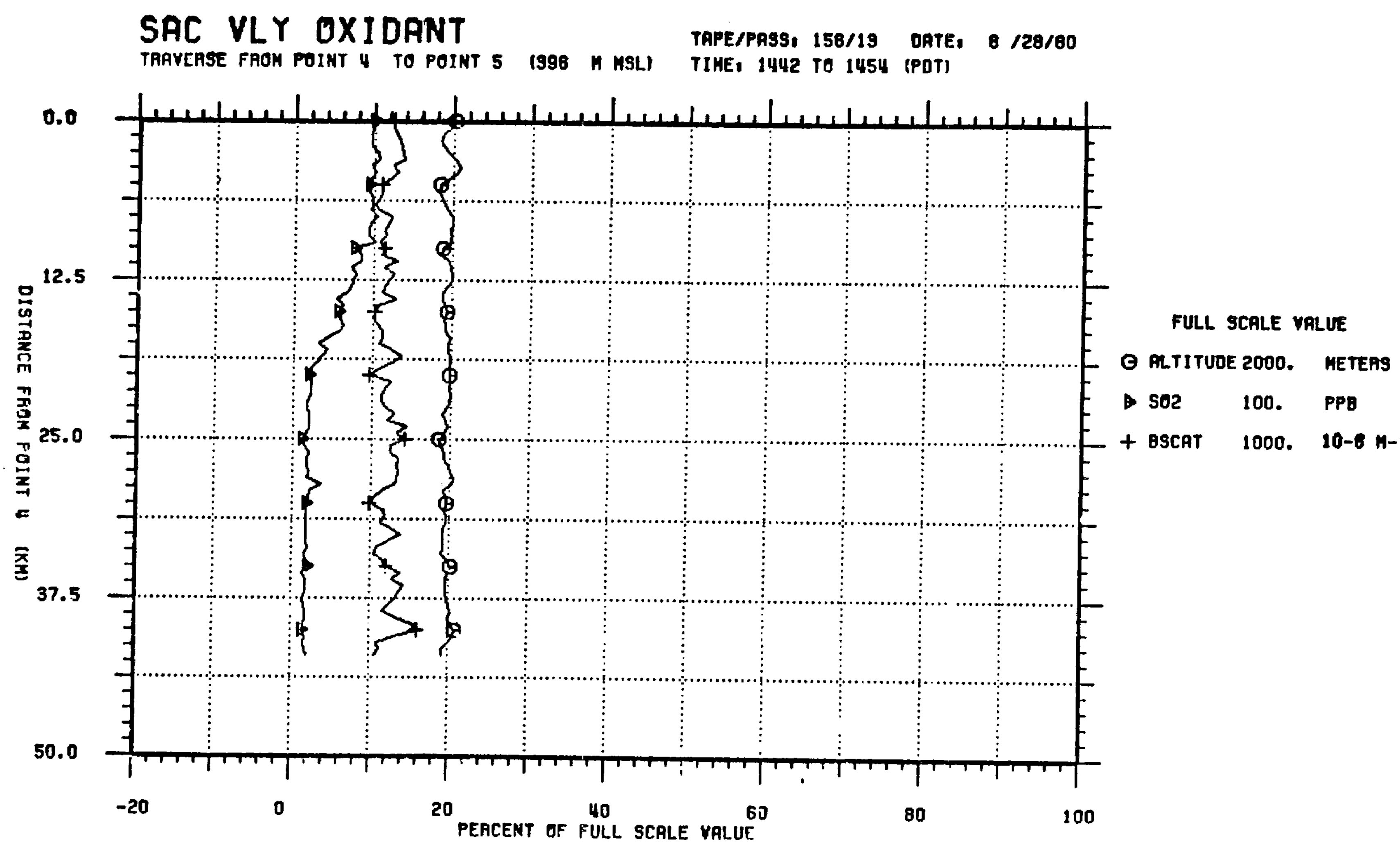

Figure 4.6.11 Airplane Traverse from Near Hood to Fair Oaks, 396 m-msl. 28 August 1980, 1442-1454 PDT. Showing SO_2, b_{scat}.

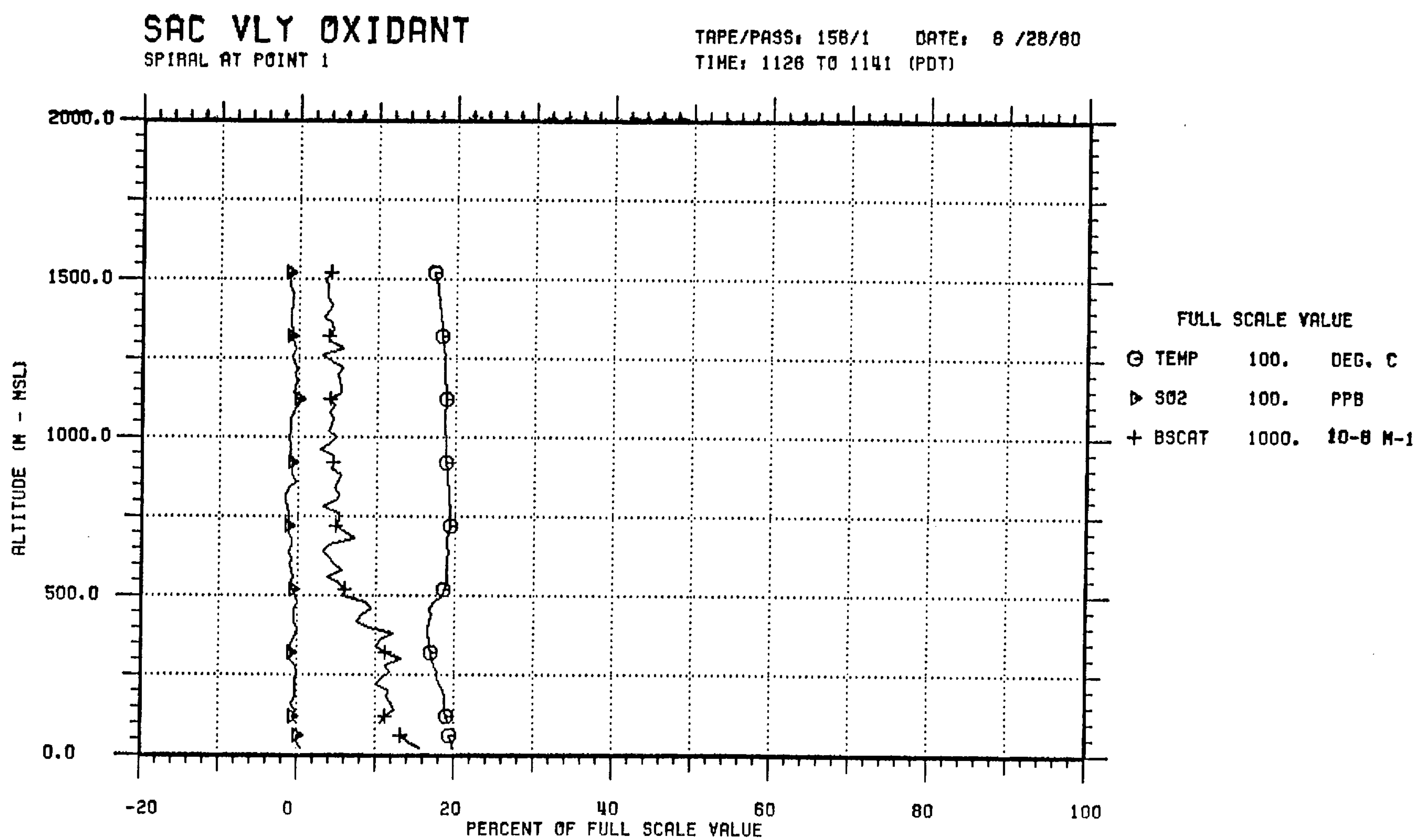

Figure 4.6.12 Aircraft Spiral 5 mi SW Sacramento Exec. AP. 28 August 1980, 1128-1141 PDT. Showing SO_2, b_{scat}, Temperature.

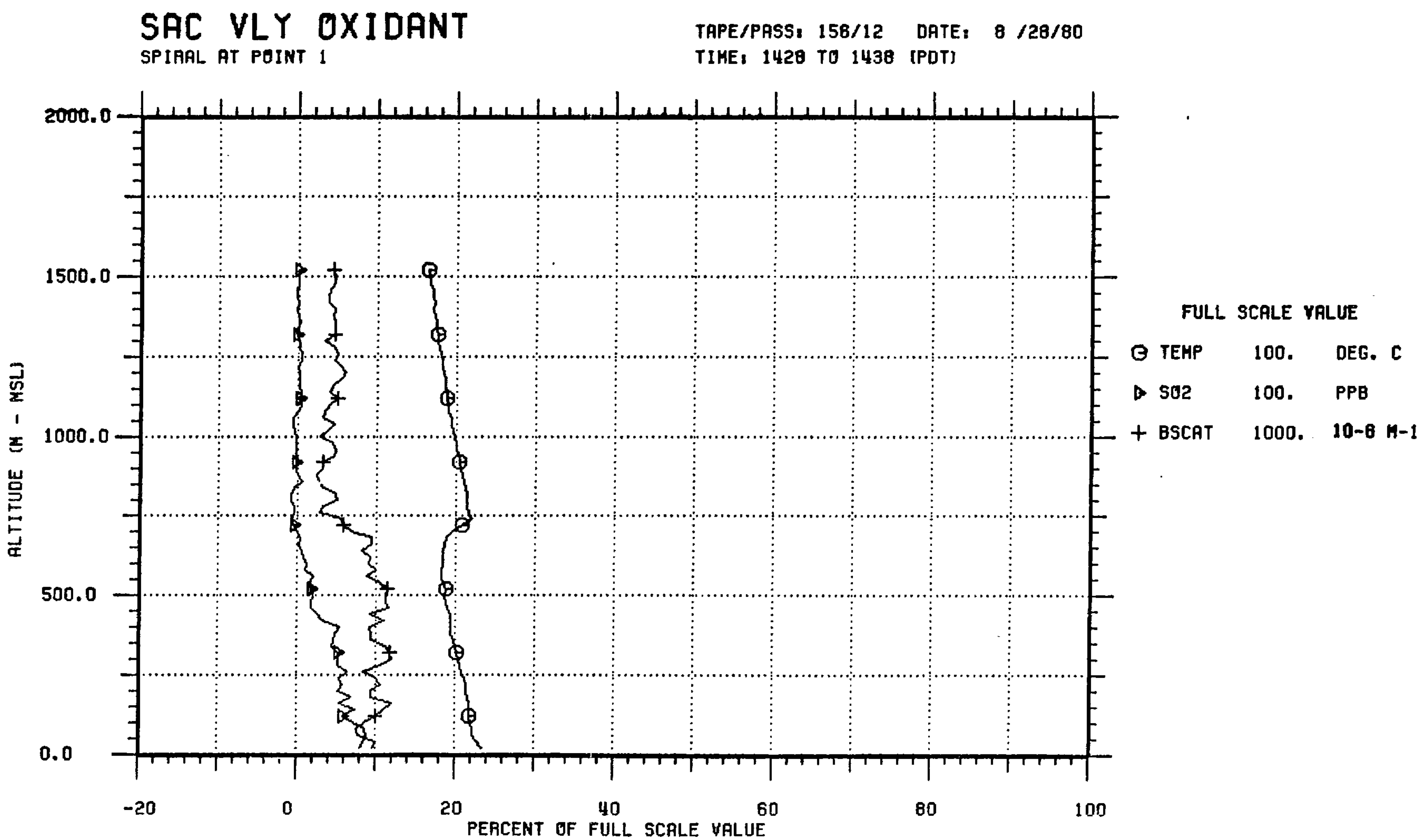

Figure 4.6.13 Aircraft Spiral 5 mi SW Sacramento Exec. AP. 28 August 1980, 1428-1438 PDT. Showing SO_2, b_{scat}, Temperature.

are shown in Figures 4.6.14 and 4.6.15. Figure 4.6.14 shows the nitrogen oxides distribution on the early traverse from Point 3 - Point 4 and Figure 4.6.15 shows the distribution of nitrogen oxides on the first traverse from Point 6 - Point 3. Within the NO_x plumes, a tracer plume was also detected, which is in good agreement with the winds discussed above. During successive sampling, the plume northwest of Sacramento was observed moving north across the Point 6-3 transect and out of the sampling region while the plume northeast of Sacramento appeared to continuously cover an area from about 9 km north of Point 5 (Fair Oaks) to 15 km west of Lincoln Airport. However, during the last orbit, the tracer plume had moved beyond the sampling region. The northwest NO_x plume was clearly composed of Sacramento area emissions although the prior history of the air included transport over Woodland. The source of the northeast NO_x plume is not clear at this time although that air had also passed over Woodland.

Regional Surface Oxidant Levels

Figure 4.6.16 shows the hourly surface oxidant concentrations for selected locations within the study area on 28 August. The data show generally good air with no exceedances of the California State Standard for ozone and generally good quality. The highest levels experienced were 9 pphm for four hours at Auburn. Late timing of the peak there indicates sources other than local. Redding again shows a peak beginning at 1100 PDT and continuing for five hours, suggesting fumigation from aged pollutants aloft by convective mixing. White Cloud, the highest elevation monitoring site, shows very low (4 pphm or less) ambient oxidant levels throughout the period.

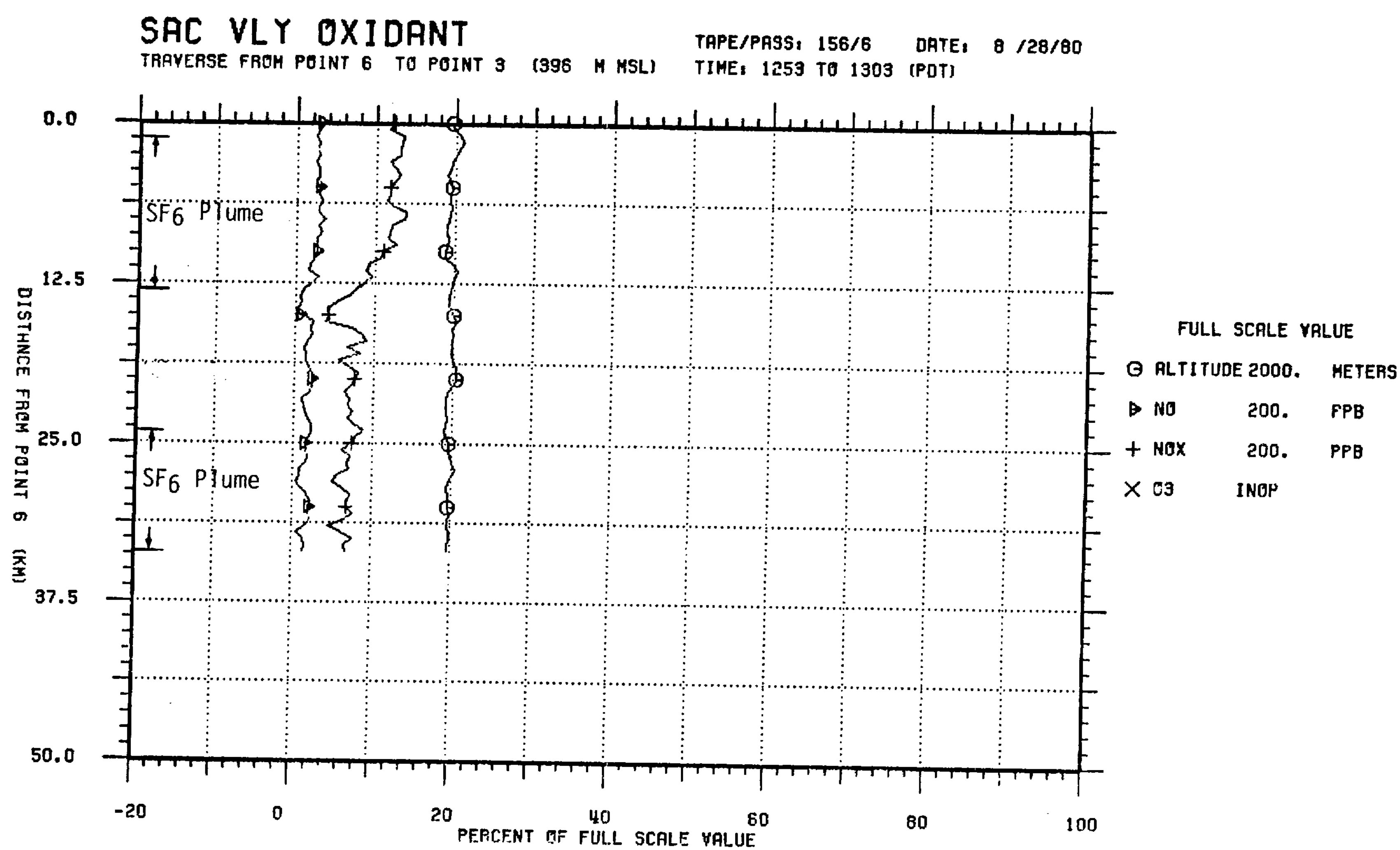

Figure 4.6.14 Airplane Traverse from Lincoln AP to Knights Landing, 396 m-msl. 28 August 1980, 1259-1303 PDT. Showing NO, NO_x, and SF_6.

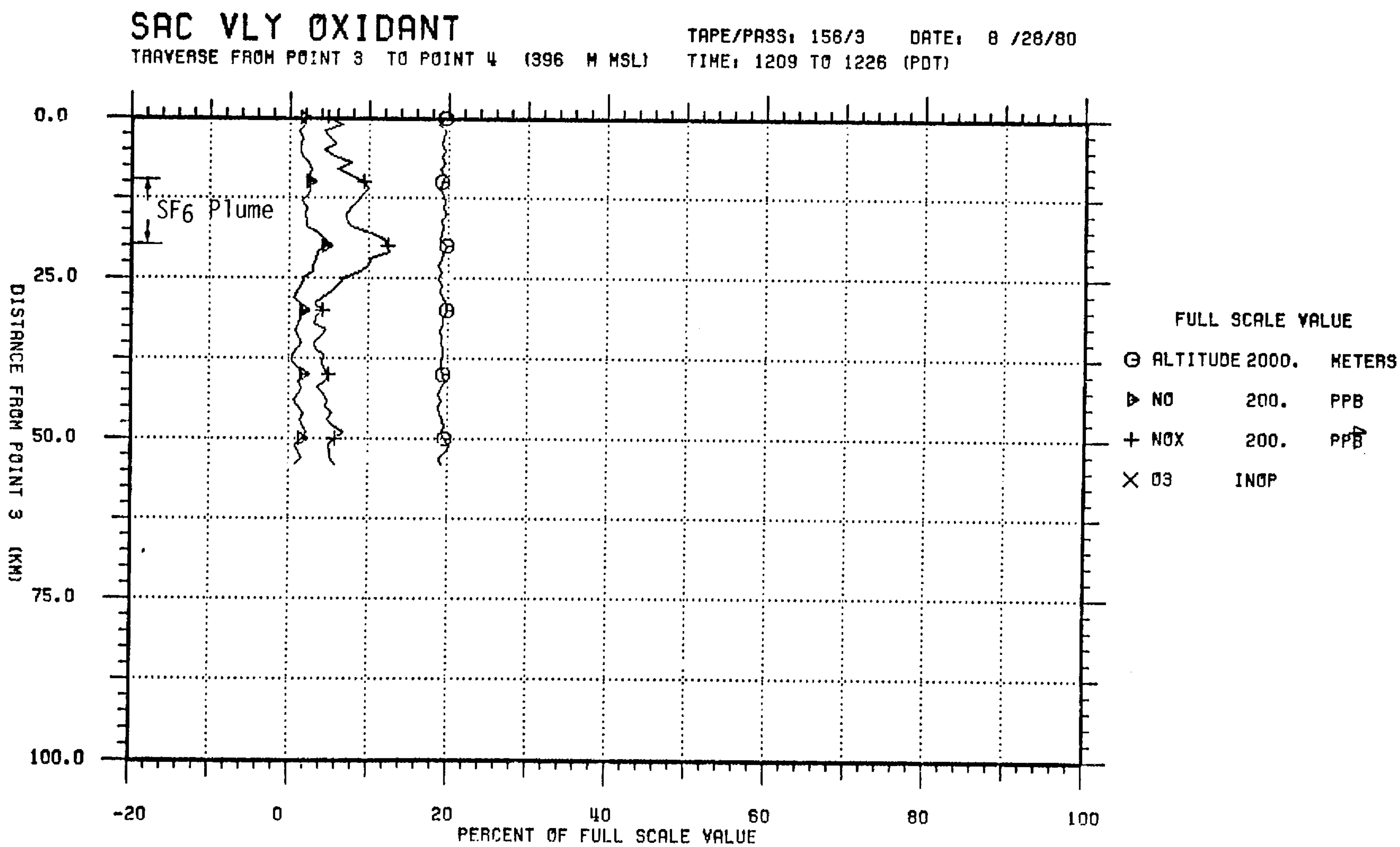

Figure 4.6.15 Airplane Traverse from Knights Landing to Near Hood, 396 m-msl. 28 August 1980, 1209-1226 PDT. Showing NO, NO_x, and SF_6.

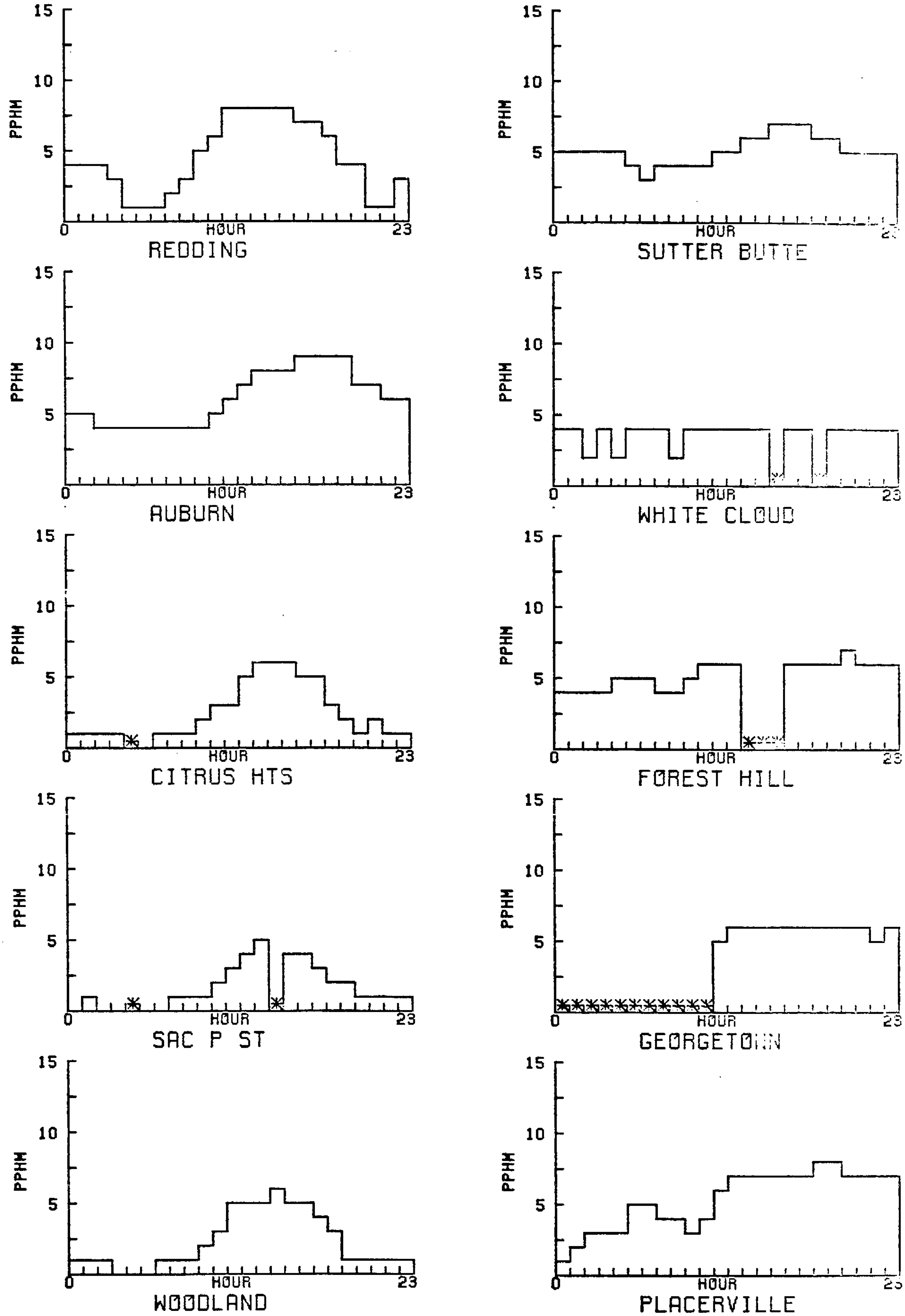

Figure 4.6.16 Hourly Averaged Oxidant Concentrations at Selected Locations. 28 August 1980. (* indicates missing data).

4.6.3 Tracer Results

Three hundred lbs of SF_6 were released from the Woodland Airport on August 28, 1980 between 0600 and 1000 PDT. The purpose of the test was to release tracer material into the Schultz Eddy and to document the subsequent transport.

A map showing the results of several of the auto traverses is given in Figure 4.6.17. Early in the release the principal impact of the tracer was in the vicinity of Davis. By 1030 PDT a portion of the tracer was observed to the north of Sacramento.

The evolution of the Schultz Eddy resulted in a gradual shift of the plume trajectory to a more easterly and then a northeasterly direction. This is shown schematically in Figure 4.6.18 in the form of several trajectories which were drawn from traverse data taken during the morning and early afternoon on August 28.

The results of this test indicate that a morning influx of air into Sacramento from the southwest can occur which involves air previously recirculated in the southern portion of the Sacramento Valley.

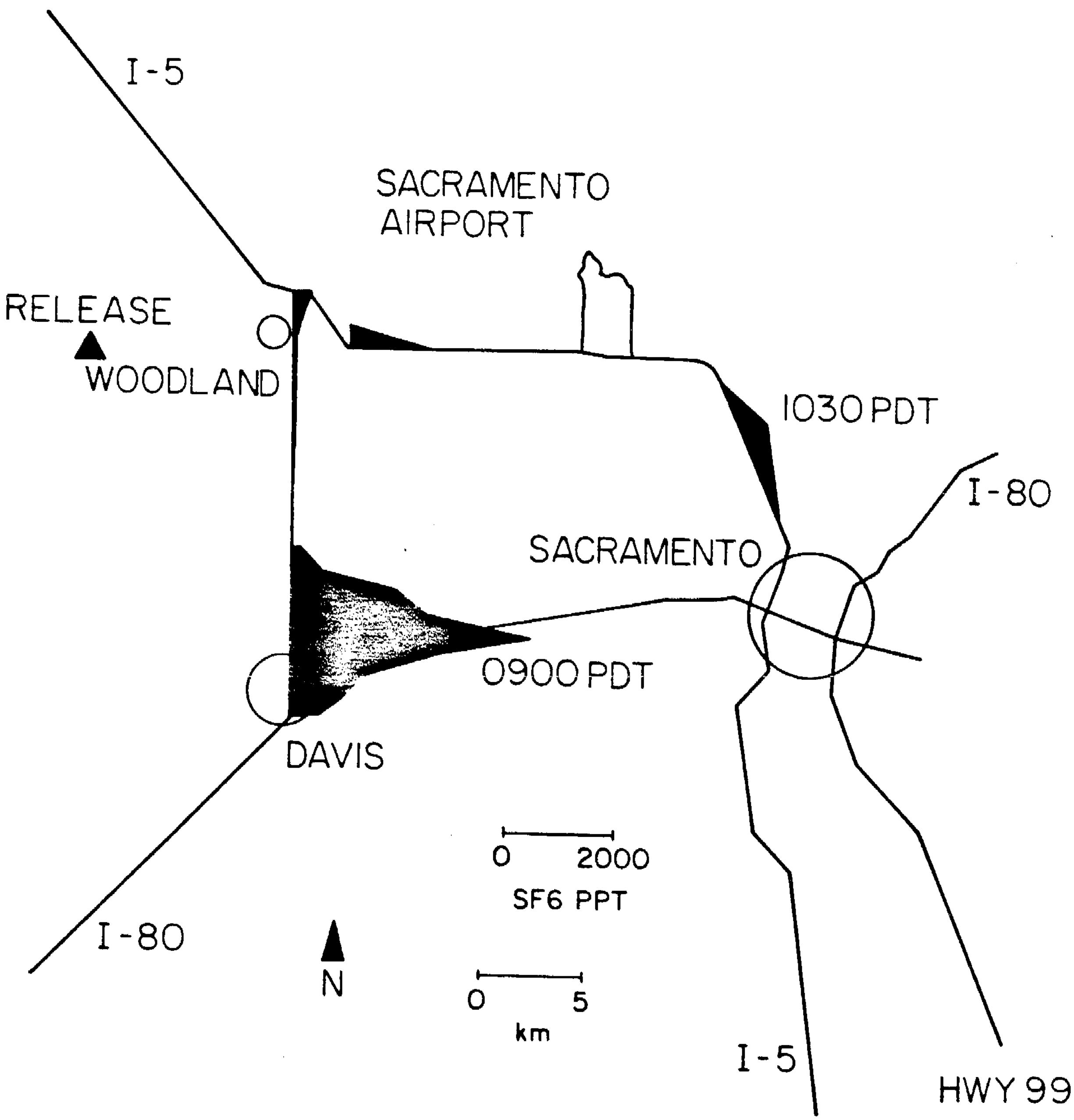

Figure 4.6.17 SF_6 Concentrations from Automobile Traverses (height of shaded region proportional to concentration) Test 6 - August 28, 1980.

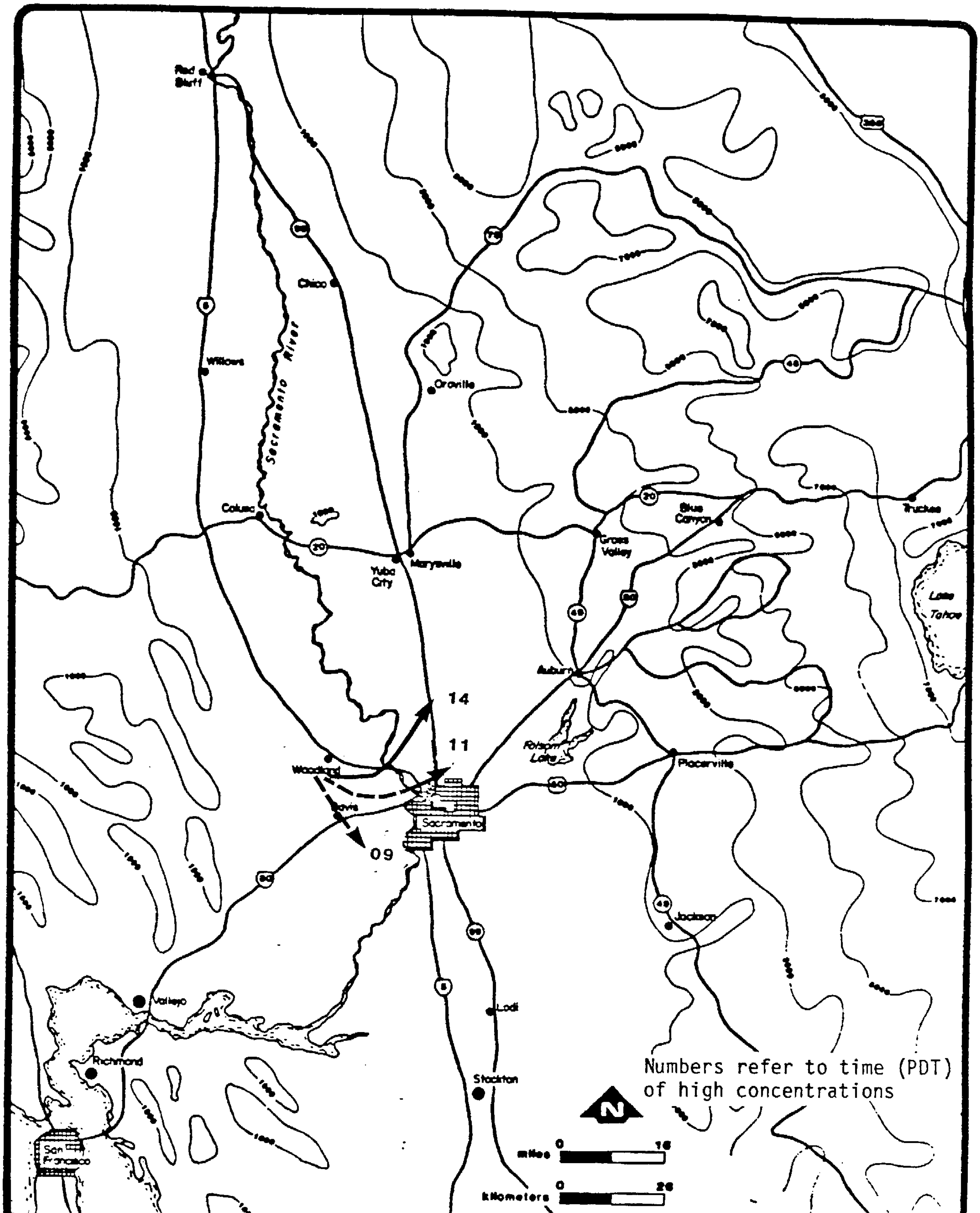

Figure 4.6.18 Tracer Trajectories - Test 6
August 28, 1980 - 0600-1000 PDT

5. Discussion of Results

An extensive data base has been acquired for use in the development of air quality models in the Sacramento Valley air basin. This base is comprised of the following data:

- Tracer releases - A total of six releases were carried out during August 1980 supported by meteorological and air quality observations.
- Air quality observations - Five sites were established during August 1980 to supplement existing observations. Ozone was continuously monitored at all sites and b_{scat} at three sites.
- Aircraft air quality and meteorological sampling - A total of 36 hours were logged regionally sampling ozone, nitrogen oxides, sulfur dioxide, b_{scat}, turbulence, temperature, and dew point. Flights were made in conjunction with each of the tracer experiments. Supplemental flights measured initial conditions during the early morning in urban and rural environments.
- Pibal wind observations - Winds aloft were measured at two-hour intervals during each tracer test from three or four locations for 24-36 hours beginning near release start times. The duration and locations of observations were dependent upon the specific test.
- Surface wind observations - Surface winds were measured at four of the air quality sites and at the tracer release site when data were otherwise unavailable. Supplemental wind data from 23 locations were obtained from a number of different public agencies.
- Acoustic radar observations - An acoustic radar was operated in the Georgetown area from 11-29 August 1980. This data provided a climatological record of the inversion formation and erosion, and of vertical mixing properties during the study period.

A brief summary of each of the tracer tests follows:

Test 1 - August 9, 1980 (Release from 4 miles northeast of Vallejo - 0620 to 1120 PDT)

The primary tracer plume was observed to pass to the south of Sacramento, reaching Lodi in the afternoon and moving into the Sierra slopes thereafter. A small amount of tracer material moved northward into the Sacramento Valley during the test and the trajectory of the plume shifted somewhat more to the north by mid afternoon. Tracer was observed during an automobile traverse in the foothills of the Sierras on the following day.

Test 2 - August 13, 1980 (Release from Sacramento - 0600 to 1100 PDT)

The tracer material was transported northward and northwestward into the Sacramento Valley, impacting strongly at Marysville and Colusa about 1300-1400 PDT and at Willows between 1500 and 1800 PDT. There was little transport to the northeast into the Auburn area. Small concentrations were observed at Redding beginning about midnight and continuing throughout the balance of the night.

Test 3 - August 20, 1980 (Release from McClellan AFB, Sacramento - 1500-1900 PDT)

The tracer material was carried directly eastward into the Sierra foothills, passing to the south of Auburn. There appeared to be little carry over of the tracer along the foothills during the night or the following morning.

On the following day, significant tracer amounts coupled with high ozone levels were observed between 1500 and 2500 ft (above ground) over the center of the Valley to the north of Sacramento. These concentrations fumigated to the ground around noon to early afternoon on August 21. Winds at the tracer level were primarily from the south such that the observed ozone and tracer material may have originated from a deep, mixed layer on the preceding day followed by a slow drift toward the north. Alternatively, some of the tracer transported up the slopes during the afternoon may have returned aloft over the Valley.

Test 4 - August 23, 1980 (Release from Vallejo - 1500-1900 PDT)

The tracer plume movement was toward the northeast, impacting strongly at Sacramento between 1900 and 2100 PDT. Thereafter, the material was carried to the north, reaching Marysville and Colusa by midnight and Chico and Willows by 0600 PDT on the following day.

As compared to Test 1 (also from Vallejo) the surface pressure gradient from Sacramento to Red Bluff was stronger during Test 4 (2.7 mb vs. 0.8 mb at 1700 PDT). This change in pressure gradient was apparently the primary factor in directing the material into the northern Sacramento Valley during Test 4.

Test 5 - August 25, 1980 (Release from Sacramento - 0700 to 1100 PDT)

The initial movement of the tracer was toward the north. A strong impact was observed at Marysville from 1200-1300 PDT. During the afternoon a portion of the material was carried toward the slopes by the afternoon upslope wind, reaching the Sierra foothills to the east of Marysville. A portion of the tracer, however stayed in the Valley during the night and was observed at Oroville and Woodland in small amounts.

Test 6 - August 28, 1980 (Release from Woodland - 0600 to 1000 PDT)

This release was made to evaluate the transport characteristics of the "Schultz Eddy." Tracer material was transported southeastward toward Davis and thence eastward toward Sacramento. By 1300 PDT a large portion of the material was located north-northwest of Sacramento and apparently moving toward the north.

The test illustrated the influence of the Eddy in recirculating pollutant material within the Valley and protecting areas such as Woodland from direct impact by the San Francisco plume during the morning hours.

The two major sources of pollutants contributing to the Sacramento Valley are the San Francisco and Sacramento urban areas. A summary of their source-receptor relationships follows:

San Francisco Plume

Results from the California Delta study (Smith, Giroux and Knuth, 1977) together with data from the present program indicate that the San Francisco plume most frequently moves through the Delta area, passing to the south of Sacramento. Lodi, Stockton and the Sierra foothills to the east of these cities appear to be most frequently impacted. Transport into the San Joaquin Valley south of Stockton may also occur.

During the present test series, results from one release from Vallejo (Test 4) indicated significant impact in the Sacramento area itself and continued transport into the Sacramento Valley including Marysville, Colusa, Chico and Williams. The existence of the tracer in the early morning of the following day at Chico and Williams indicated that cary-over pollutants from the Bay area can be available for photochemical reactions on the following day.

Sacramento Plume

Release from Sacramento showed a variety of trajectories, ranging from easterly to northerly or northwesterly. During the two morning releases (prior to 1100 PDT) the material was carried northward, strongly impacting Marysville and other locations to the north of Sacramento. On one occasion this material was picked up by the upslope flow in the afternoon. In the other case (Test 2) most of the tracer stayed in the Valley reaching as far north as Redding during the night.

The afternoon release from Sacramento (Test 3) impacted the Sierra foothills directly east of Sacramento. On the other hand, the most frequent ozone impact from Sacramento appears to be in a northeasterly direction toward Auburn (Duckworth and Crowe, 1979). It therefore appears that the summer impact of the Sacramento plume can vary from an easterly through northerly direction, depending on time of day and perhaps pressure gradients. The slopes of the Sierras can be affected for a distance of at least 50-75 miles to the north of Sacramento.

Evidence was found during one test (Test 3) of carry-over from the Sacramento into the northen Sacramento Valley on the day following the tracer release.

Tracer Diffusion Data

Tracer data obtained from automobile and aircraft traverses were used to characterize the diffusion processes occurring during each of the tests. Cloud widths were obtained from each of the traverses when the entire tracer plume had clearly been traversed. Cloud widths along the traverse route were corrected when the route was not perpendicular to the trajectory of the plume. Peak concentrations for each traverse were taken as the highest observed concentration along the route. No attempt was made to do curve-fitting for the concentration data. Wind speeds correspond to surface winds at or near the site adjusted for the travel time to the location of the traverse.

Tracer concentrations have been normalized into standard diffusion format ($\chi u/Q$) where χ is the concentration, u is the wind speed and Q the source strength. Units of $\chi u/Q$ are m^{-2}. Values of $\chi u/Q$ at given distances downwind can be compared to predictions using Pasquill stability categories. The equivalent stability categories based on the calculated $\chi u/Q$ values are given in Table 5.1 together with a summary of the pertinent tracer data taken from auto traverses.

The same type of information using hourly tracer concentration data is given in Table 5.2. Due to the spacing of the hourly samplers, plume centerline concentrations are rarely observed and only a limited amount of data is suitable for this type of analysis.

All of the observed concentrations correspond to Pasquill stability categories C, D, or E. It is noticeable in the table that the light wind speeds are more frequently associated with C and D categories. Stronger wind speeds (Tests 2, 4, and 5) show characteristically more frequent D to E categories. It is assumed that this shift in category with a change in wind speed results from the tendency of the tracer plume to meander under light winds with a consequent dilution of the plume concentrations.

The predominance of E stability categories during daytime heating conditions may, at first, be surprising. For long downwind distances, however, the upward growth of the plume is restricted and the surface plume concentrations remain somewhat higher than might otherwise be expected. This restriction due to mixing layer depth becomes significant at downwind distances beyond 10-20 km.

Table 5.1

Tracer Diffusion Data

Time PDT	Downwind Distance (km)	Cloud Width (σ_y - km)	Wind Speed (m/s)	Xu/Q (m^{-2})	Estimated* Stability
Tests 1 - August 9, 1980					
0825	8.8	0.93	2.0	0.054×10^{-5}	C
0855	8.4	0.84	2.0	0.095	C
0910	8.4	0.63	2.0	0.098	C
1050	8.4	0.50	2.5	0.425	E
1140	8.4	0.84	1.5	0.197	D
1415	32.2	3.72	2.0	0.007	C
1255(a/c)	25.7	4.42	2.0	0.012	C
Test 2 - August 13, 1980					
0900	3.2	0.61	6.1	0.847	C
0920	11.3	0.50	6.1	0.457	D
1030	14.5	0.88	6.1	0.726	E
1320	53.1	4.76	6.6	0.132	E
1630	111.0	2.91	5.6	0.034	E
1840	135.2	3.36	5.1	0.046	E
Test 3 - August 20, 1980					
1740	12.1	1.80	2.0	0.068	C
1745	9.6	1.45	2.6	0.164	C
2115	35.4	2.74	2.6	0.016	C

*Estimated from Tracer Concentrations

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Table 5.1 (Continued)

Test 4 - August 23, 1980					
1640	8.0	0.85	6.3	0.239	C-D
1640	8.0	1.00	6.7	0.482	D
1800	20.1	1.00	6.7	0.389	E
1825	20.9	1.00	6.7	0.248	E
1930	38.6	2.78	6.7	0.121	E
1950	72.4	8.69	6.3	0.050	E
2000	70.8	4.42	6.7	0.147	E
2100	70.8	7.45	6.7	0.107	E
2320	107.8	8.85	6.1	0.067	E
2345	103.0	4.59	6.1	0.079	E
Test 5 - August 25, 1980					
0820	3.2	0.37	4.6	0.934	C-D
0850	3.2	0.42	4.6	1.035	C
0900	3.2	0.34	4.6	1.127	C
0915	8.0	0.53	4.6	0.828	D-E
0925	8.0	0.68	4.6	0.750	D
1010	8.8	0.53	5.1	0.648	D
1035	22.5	0.68	4.6	0.428	E
1115	8.0	0.71	4.1	0.377	D
1155	37.0	1.01	4.6	0.133	E
1500	72.4	6.26	4.6	0.023	D
1700	67.6	4.71	4.1	0.016	D
1435(a/c)	27.4	1.66	4.1	0.010	C-D
Test 6 - August 28, 1980					
1005	8.0	1.22	3.5	0.406	C
1035	37.4	1.64	3.5	0.052	D
1105	27.4	1.30	3.5	0.073	D
1205	22.5	0.92	3.5	0.248	E
1240	14.5	1.59	1.6	0.067	C
1415	28.2	1.95	2.1	0.061	D
1210(a/c)	6.4	1.29	3.5	0.133	C

Table 5.2

Hourly Tracer Diffusion Data

Time PDT	Downwind Distance (km)	Wind Speed (m/s)	Xu/Q (m^{-2})	Calculated Stability
<u>Test 2 - August 13, 1980</u>				
1300 (Marysville)	61	6.6	6.2×10^{-7}	D-E
<u>Test 4 - August 23, 1980</u>				
2100 (Sacramento)	77	6.3	6.5×10^{-7}	E
0100 (Marysville)	117	6.1	3.6	E
0000 (Colusa)	136	6.1	3.8	E
<u>Test 5 - August 25, 1980</u>				
1300 (Marysville)	61	4.6	3.7×10^{-7}	D

The concentration data and equivalent stability information given in the table should be of value for modeling of long-range impact of pollutant sources in the Sacramento Valley.

Pollutant Loadings

Average pollutant concentrations have been calculated from each aircraft spiral in the layers 0 to 500 m and 500 to 1000 m above ground level. The total pollutant loadings in vertical columns 500 m deep were then obtained by combining the average concentrations with the depth of the layer. Results are shown in Table 5.3. Ozone loadings were calculated above a mean ambient background concentration of 5 to 5.5 pphm as estimated from the upper portions of the soundings. Negative ozone loadings reflect the scavenging of low-level ozone concentrations by NO.

Comments on the characteristics of the individual days follow:

August 9 - Low-level loadings of NO and NO_x were relatively high during the late morning soundings but decreased substantially in later soundings due largely to increased vertical mixing. Highest values were observed at Sacramento and Antioch. Reduced low-level ozone concentrations were observed at Sacramento and Antioch in the first two soundings. Values increased substantially in all soundings by early afternoon, partly due to diurnal changes in mixing and perhaps due to changes in local urban, scavenging effects. Highest SO_2 value was observed at Antioch during the 1158 PDT sounding.

August 13 - Early morning soundings at Sacramento and Rio Linda were similar in most parameter values. Ozone scavenging was pronounced in the lowest 500 m in both soundings. Somewhat more ozone existed aloft (500-1000 m) at Sacramento. Otherwise the two areas (southwest and northwest of Sacramento) appeared very similar.

The afternoon soundings were made downwind of Sacramento in the urban plume. Soundings made at Lincoln and farther downwind at Big Oak Valley Airport show typical urban plume developments. Ozone loadings increase with downwind distance while all other parameter loadings (0 - 1000 m) decrease. The Georgetown sounding was made much farther up the slope (elevation near 900 m). Loadings at this location were generally lower than at either of the other sites indicating that the main plume moved in a more northerly direction.

Table 5.3

Pollutant Loadings (mg/m^2)

Date	Location	Time (PDT)	Layer (km)	NO	NO_x	O_3	SO_2	b_{scat}**
8/9	Sacramento Pt. 1*	1112	0.0-0.5	4.6	15.4	0	2.6	.065
			0.5-1.0	2.3	3.2	25.5	1.9	.020
	Antioch Pt. 2	1158	0.0-0.5	2.9	16.4	-10.0	11.8	.050
			0.5-1.0	2.3	3.2	17.5	3.9	.025
	Travis Aero Pt. 3	1231	0.0-0.5	2.3	11.3	19.5	2.6	.055
			0.5-1.0	1.1	4.7	19.5	1.9	.015
	Travis AP Pt. 6	1344	0.0-0.5	1.1	8.3	33.5	1.3	.055
			0.5-1.0	1.1	2.9	21.5	1.3	.020
	Sunset Sky Ranch Pt. 7	1415	0.0-0.5	2.3	5.9	27.5	1.3	.050
			0.5-1.0	1.1	4.7	33.5	1.3	.015

* Refer to Figure 4.1.6 for Pt. locations
** Dimensionless units
(O_3 background 5 pphm)

Date	Location	Time (PDT)	Layer (km)	NO	NO_x	O_3	SO_2	b_{scat}**
8/13	Sacramento	0620	0.0-0.5	0.5	8.1	-21.5	0.4	.085
			0.5-1.0	0.5	2.7	25.5	0.1	.030
	Rio Linda	0656	0.0-0.5	2.3	9.0	-23.5	0.1	.065
			0.5-1.0	0.1	2.5	7.5	0.0	.025
	Lincoln Pt. 5*	1500	0.0-0.5	2.9	13.5	35.5	2.6	.065
			0.5-1.0	2.3	3.6	23.5	1.9	.030
	Big Oak Pt. 10	1655	0.0-0.5	2.3	10.8	53	0.6	.047
			0.5-1.0	1.7	5.4	30.5	0.6	.020
	Georgetown Pt. 11	1722	0.0-0.5	2.3	2.7	29.5	0.2	.015
			0.5-1.0	2.3	0.9	0	0	.007

* Refer to Figure 4.2.6 for Pt. locations
(O_3 background 5 pphm)

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Table 5.3 (Continued)

Date	Location	Time (PDT)	Layer (km)	NO	NO_x	O_3	SO_2	b_{scat}**
8/20	Sunset Sky Ranch	0632	0.0-0.5	0.2	3.5	-16	6.5	.070
			0.5-1.0	0.1	0.1	14.5	1.9	.067
	Rio Linda	0728	0.0-0.5	1.1	5.6	-18.5	1.9	.070
			0.5-1.0	0.1	0.1	18.5	1.3	.060
	Sacramento Pt. 1*	1524	0.0-0.5	1.1	2.9	28.5	0.5	.052
			0.5-1.0	1.1	2.0	28.5	0.6	.050
	Phoenix Pt. 4	1706	0.0-0.5	0.4	6.0	42	0.1	.055
			0.5-1.0	0.2	6.2	36	0.1	.052
	Folsom Lake Pt. 8	1808	0.0-0.5	0.2	7.1	56	0.5	.070
			0.5-1.0	0.1	7.1	40	0.5	.055
	Auburn Pt. 9	1833	0.0-0.5	0.1	4.4	57.5	0	.070
			0.5-1.0	0.1	2.6	36	0.4	.055

* Refer to Figure 4.3.6 for Pt. locations
** Dimensionless units
(O_3 background 5.5 pphm)

Date	Location	Time (PDT)	Layer (km)	NO	NO_x	O_3	SO_2	b_{scat}**
8/21	Sacramento Pt. 1*	1120	0.0-0.5	1.7	8.0	- 6	1.9	.050
			0.5-1.0	0.5	3.2	19.5	1.3	.030
	Marysville Pt. 2	1210	0.0-0.5	1.7	9.8	25.5	1.9	.060
			0.5-1.0	1.3	6.7	49	1.3	.085
	Red Bluff Pt. 6	1409	0.0-0.5	1.7	8.0	53	1.3	.055
			0.5-1.0	1.7	6.2	45	1.3	.050

* Refer to Figure 4.3.6 for Pt. locations
(O_3 background 5 pphm)

Date	Location	Time (PDT)	Layer (km)	NO	NO_x	O_3	SO_2	b_{scat}**
8/23	Sacramento Pt. 1*	1715	0.0-0.5	2.3	5.9	22.5	5.4	.067
			0.5-1.0	1.7	4.4	32	1.9	.052
	Nut Tree Pt. 2	1800	0.0-0.5	1.7	6.2	- 7	1.9	.050
			0.5-1.0	0.5	0.7	10.5	0.6	.047
	13 S Sac Pt. 4	1856	0.0-0.5	1.7	6.2	- 5	1.3	.045
			0.5-1.0	1.3	3.1	28.5	1.3	.055

* Refer to Figure 4.4.7 for Pt. locations
(O_3 background 5.5 pphm)

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Table 5.3 (Continued)

Date	Location	Time (PDT)	Layer (km)	NO	NO_x	O_3	SO_2	b_{scat}**
8/25	Sacramento	0623	0.0-0.5	1.3	2.2	-13.5	3.9	.070
			0.5-1.0	0	0.9	11	0.2	.045
	Phoenix	0653	0.0-0.5	2.3	9.5	-23.5	5.2	.070
			0.5-1.0	0.4	1.5	0	0	.040
	Rio Linda	0715	0.0-0.5	2.3	13.1	-17.5	2.6	.070
			0.5-1.0	0.2	0.8	4	0	.035
	Sacramento Pt. 1*	1351	0.0-0.5	1.7	2.6	- 2	0.6	.045
			0.5-1.0	0.4	0.6	12	0	.030
	W Folsom Lake Pt. 6	1518	0.0-0.5	1.7	9.8	45	10.5	.045
			0.5-1.0	1.7	7.1	41	5.2	.040
	N Folsom Lake Pt. 7	1545	0.0-0.5	1.3	4.9	47	9.1	.047
			0.5-1.0	0.5	3.2	39	2.6	.040
	6 NE Auburn Pt. 8	1605	0.0-0.5	2.3	9.5	43	3.9	.045
			0.5-1.0	1.7	8.0	45	2.6	.040
	Georgetown Pt. 11	1657	0.0-0.5	1.3	4.0	37	1.3	.035
			0.5-1.0	1.3	4.0	32.5	0.6	.040

* Refer to Figure 4.5.5 for Pt. locations
** Dimensionless units
(O_3 background 5 pphm)

Date	Location	Time (PDT)	Layer (km)	NO	NO_x	O_3	SO_2	b_{scat}**
8/28	Sacramento Pt. 1*	1126	0.0-0.5	1.3	6.7		0	.045
			0.5-1.0	0.2	1.7		0	.020
	15 NW Sac Pt. 2	1151	0.0-0.5	2.3	13.1		0.5	.065
			0.5-1.0	0.5	5.9		0	.040
	15 NW Sac Pt. 2	1400	0.0-0.5	1.3	6.7		2.6	.040
			0.5-1.0	0.2	3.5		0.6	.020
	Sacramento Pt. 1	1428	0.0-0.5	1.3	8.5		6.5	.050
			0.5-1.0	0.2	2.9		0.6	.037

* Refer to Figure 4.6.8 for Pt. locations

August 20 - Morning soundings were made to the south and north-northwest of Sacramento. Total pollutant loadings were quite similar except that a substantially higher SO_2 value was observed at Sunset Sky Ranch to the south of Sacramento. Low-level ozone scavenging was apparent at both locations.

Afternoon spirals wre made over and downwind of Sacramento as far as Auburn. Ozone loadings increased with downwind distance in the urban plume with Auburn and Folsom Lake indicating the highest but similar values. NO_x values also increased with downwind distance from Sacramento to Folsom Lake but decreased at Auburn.

August 21 - Soundings were made in the late morning and early afternoon at Sacramento, Marysville and Red Bluff. Ozone loadings increased from Sacramento to Red Bluff. However, a time difference of nearly three hours may have contributed to the ozone differences. The balance of the parameter loadings were similar in all three locations.

August 23 - Three soundings were made in the late afternoon or evening along a west-northwest to east-southeast line slightly upwind of Sacramento. Total distance between end points of the line was about 27 miles. The total ozone loadings were highest near Sacramento and lowest during the spiral at Vacaville. Similar comparisons were apparent in the remaining parameters. Ozone scavenging was observed, particularly, at Vacaville and south of Sacramento.

August 25 - Morning soundings were made near Sacramento, at Rio Linda and at Phoenix Airport. The layer from 500 to 1000 m was unusually clean at all locations. Low-level ozone scavenging was observed at all three sites. NO_x values in the lowest layer were highest at Rio Linda.

Afternoon soundings were made near and downwind of Sacramento. Ozone loadings downwind of Sacramento were higher than observed earlier at Sacramento. Somewhat reduced values of ozone were measured at Georgetown in agreement with the urban plume results obtained on August 13. SO_2 loadings, however, decreased steadily in a downwind direction. Strong vertical mixing within the lowest 1000 m was evident from the similar loading values obtained within each layer at each site.

August 28 - Soundings were made during the late morning and early afternoon near Sacramento and about 15 miles to the northwest. Two soundings were carried out at each location with 2-3 hours separating the sampling at the same site. Primary changes observed were in low-level SO_2 which increased significantly at both sites between successive samplings. Ozone concentrations were not measured due to an inoperative instrument.

Ozone Flux Calculations

The ozone flux which could be attributed to the Sacramento urban area can be computed from aircraft soundings and pibal data if successive soundings were made in similar parcels of air. These conditions were reasonably well fulfilled on August 20 (Test 3) at Sacramento and Auburn. The mass concentration of ozone or flux of ozone passing through a vertical plane is given by the relationship:

$$M = \int_{z_2}^{z_1} \int_{x_1}^{x_2} u \chi \, dx dz \qquad (1)$$

where z = position along the vertical axis

x = position along the horizontal axis

u = component of the wind perpendicular to the plane, and

χ = mass per unit volume

Flux attributable to urban emissions is related to the difference between ozone burden upwind and downwind of the source ($\Delta\chi$). Thus, to calculate ozone production or increase per horizontal distance within the mixed layer, equation (1) can be approximated by

$$\Delta M(km^{-1}) = \Delta\chi \bar{u} H, \text{ where} \qquad (2)$$

$\bar{u}$ = average component of wind from the surface to the top of mixing, and

H = mixing height

In this case, using (2), the net increase in ozone flux was .34 metric tons hr^{-1} km^{-1}. By comparison, Smith, et al. (1981) computed in a similar manner for a worst observed case of the Bakersfield plume, 2.10 metric tons hr^{-1} km^{-1}. However, Bakersfield at that time was experiencing 10°F warmer temperatures, a deeper mixing layer (1200 m) and over 50% greater wind speed. The difference in ozone flux between Bakersfield and Sacramento reflects the differences in meteorological conditions which affect ozone formation and transport.

6. Conclusions

1. Under the conditions of the tracer tests, early morning emissions from the San Francisco Bay area and the Delta had a limited effect on air quality in the Sacramento Valley. Characteristic transport patterns in the morning usually carry the pollutants eastward into the Sierra foothills or southeastward into the San Joaquin Valley. The frequent presence of the Schultz Eddy helps to maintain the flow pattern from the Bay area in an easterly direction. This pattern, however, may be interrupted by marked changes in the N-S pressure gradient in the Valley.

2. During the afternoon with increased heating in the Sacramento Valley and the breakdown of the Schultz Eddy, the impact of emissions from the Bay area into the Valley tends to become more significant. Tracer results from Test 4 showed a major impact from emissions at Vallejo as far north as Willows, Chico and Oroville. The N-S pressure gradient in the Valley was strongly directed from Sacramento to Red Bluff, however, so that the upvalley tracer impact should have been unusually large on that day.

3. The downwind impact of tracers released from Sacramento varied from the northern Valley to foothill locations east of the city, depending primarily on time of day. Early morning releases moved northward toward Marysville and Oroville. Afternoon releases were carried eastward or northeastward in response to the heating of the Sierra slopes.

4. Evidence was found of a slight carry over of tracer material in the Valley or in the Sierra foothills in Tests 1, 2 and 3. In Test 5 considerable tracer material from a Sacramento release was observed as late as 0200 PDT near Red Bluff. No

traverses were made in the area on the following morning but extensive carry over is likely. In Test 4 the carry over from a Vallejo release was widespread throughout the Valley in the vicinity of Red Bluff - Oroville - Willows. As noted, this test exhibited unusually strong south to north pressure gradients during the afternoon of the release. These data suggest that carry over of ozone or precursors in the Sacramento Valley into the following day may be more important from Sacramento emissions then from the Bay area although (e.g., Test 4) unusual conditions may bring an extensive impact from the Bay area.

5. A mechanism exists for the transport and entrapment of pollutants from Sacramento in elevated layers over the Valley. The pollutants carried aloft can lead to ground level impacts on the following day as the surface mixing layer grows to include the polluted layer. The transport of pollutants aloft may be linked to the afternoon upslope flow on the foothills of the Sierra Nevada, or from the existence of a deep, slowly moving, mixed layer during the preceding afternoon.

6. The Schultz Eddy develops frequently in the southern part of the Valley between Chico and Sacramento. The strongest period of development appears to be during the early morning and forenoon. The mechanism for development is related to opposing down-valley and upvalley flows which frequently interact in the area south of Chico. The eddy provides a mechanism for recirculating pollutants from the Sacramento area toward the west and southwest regions of the Valley. The eddy also tends to restrict air from the Bay area from entering the Sacramento Valley until it breaks down in the late forenoon.

7. The most severely impacted area from the Sacramento ozone plume was found to be in the Sierra foothills between Highway I-80 and just south of Folsom Lake. Ozone concentrations in excess of 12 pphm were measured as far as 135 km from downtown Sacramento.

8. In the Sierra foothills, upslope flow generally developed by 10-11 PDT and ceased between 18-19 PDT. During the current study, 17-18 PDT was generally the time of maximum impact from the Sacramento urban plume along the western edge of the Sierra foothills. It then seems unlikely that the urban air has time to invade very deep into the mountains. The ridge top air quality sites, in fact, showed generally good air quality throughout the study period.

9. Urban air impacting in the Sierra foothills can be subsequently transported north via two mechanisms. There is evidence that low level air from the foothills can be entrained in the nocturnal jet existing over the Valley and subsequently transported over long distances to the north. In addition, at night after the upslope flow diminishes, winds upvalley and parallel to the orientation of the mountains develop. This air most likely moves upslope farther north on the following day or may escape through one of the low level gaps in the barrier such as along the Pit and Feather Rivers.

10. Due to the 24 hour persistence of the marine air intrusion into the Sacramento Valley, which dominates the flow in the Sacramento area, pollutants trapped under the nocturnal inversion generally do not have the opportunity to accumulate in the Sacramento area.

11. Typically, mixing heights in the Valley are spacially uniform. Thus, for modeling purposes one measurement may represent a large area. Tracer concentrations far downwind, however, indicate the effects of restricted vertical mixing with higher concentrations observed than expected from standard Gaussian calculations.

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